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POND INLET GARDENS

A REPORT ON THE DESIGN AND OPERATION OF A SOLAR GREENHOUSE ON NORTH BAFFIN ISLAND, NWT, WITH PARTICULAR REFERENCE TO ECONOMIC VIABILITY OF VEGETABLE PRODUCTION FOR ARCTIC REGIONS.

Prepared for:

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TABLE OF CONTENTS

SECTION 1 : INTRODUCTION

SECTION 2 : DESCRIPTION OF GREENHOUSE STRUCTURE AND SYSTEMS

SECTION 3 : PERFORMANCE OF THE GREENHOUSE (CLIMATE AND CONTROL SYSTEMS)

SECTION 4 : PLANT PERFORMANCE AND GROWTH SYSTEMS

SECTION 5 : ECONOMIC ANALYSIS

SECTION 6 : RELATED BENEFITS OF THE GREENHOUSE

SECTION 7 : CONCLUSIONS AND RECOMMENDATIONS

LIST OF FIGURES

LIST OF TABLES

LIST OF PHOTOS

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SECTION 1 : INTRODUCTION

H NORTHERN AGRICULTURE : AN ALTERNATIVE TO FOOD IMPORTATION ?

The problem of high food costs in northern communities has become increasingly serious in recent years. A number of factors are responsible for this situation.
Over the past decade, northern diets have shifted away from a heavy reliance on country foods towards an increased utilization of store-bought products imported from the south. Over the same period, shipping costs to northern communities have increased steadily, thus boosting the prices of essential commodities to very high levels.
The rise in cost of ‘fresh” perishable produce such as vegetables has been particularly drastic, reaching astronomical levels in recent years. In Pond Inlet, for example, one head of lettuce may retail for as much as $7.00-$8.00. Such high prices invariably limit the availability of fresh produce to some northerners on low or fixed incomes. Yet despite the high costs, vegetables are quickly purchased when they become available. This suggests that imported vegetables, non-existent in the traditional diet, have gained acceptance and appreciation by northerners and have in fact become essential to balanced nutrition in the recent modified diet.

High prices have placed a burden on consumers and governments alike. In order to reduce food costs to northern consumers, government transport subsidies for the shipping of perishable food items have been instituted. At present these subsidies are in the order of $40,000 per year for Pond Inlet alone and could be increased substantially in future years.

Northern agriculture in the form of greenhouse and market gardens may represent a viable alternative to expensive imported foodstuffs. Current economic strategies are tending towards import substitution and development of decentralized local industry. Greenhousing represents a non-traditional ‘business which may contribute to the diversification of the limited local economic base and increase the self-sufficiency of northern communities.

There are strong incentives supporting the development of a community greenhouse industry in arctic communities:

- Locally-produced vegetables are invariably fresher in quality and richer in nutrients than imports which may arrive several weeks after harvest.
- The increased availability and utilization of fresh vegetables may contribute to an improvement in diet and nutrition of northerners.
- Greenhouses represent a new local source of equal-Opportunity employment. The development of seasonal market gardens may also provide training and employment for part-time workers such as summer students.
- Arctic greenhouse projects may become centres for research and development of alternate technologies. Development and testing of solar heat collection and storage systems, waste heat utilization and hydroponic culture are among the many areas of potential involvement.
- As educational tools, greenhouses and gardens provide northern school students with direct exposure to the fields of biology, nutrition. technology and other sciences.
- Polar greenhouses are interesting tourist attractions and may be therapeutic in nature by providing local residents with a welcome ‘breath of summer" during the long, dark winter months.
- Development of small businesses related to the greenhouse may include the processing of produce (canning, pickling, freezing), selling of houseplants and cut flowers, cooking and gardening courses, and supplying local gardening projects.

The development of a comprehensive northern agricultural program is contingent upon the evaluation of a number of factors including:

[A] Horticultural and Technical Viability

[B] Economic Feasibility

[C] Community Awareness and Acceptance

The following section summarizes the efforts and progress made up to the present time in these areas.

1-2 ARCTIC AGRICULTURAL EFFORTS: A BRIEF HISTORY

i-2-1 EARLY EFFORTS

Agricultural efforts in Canada's arctic regions date back over 300 years. The earliest attempts at vegetable production were made by traders and missionaries in an effort to supplement their diets with fresh produce. Employees of the Hudson's Bay Company at numerous bayside posts successfully grew a wide range of crops including potatoes, onions, carrots, lettuce, turnips and radishes in crude gardens **(Moodie,** 1978) .

Research into northern agriculture was initiated in the early **1900's** with the **establ**ishment by Agriculture Canada of a number of experimental stations in the Yukon and **NWT.** By 1950, five substations were operating at **Inuvik, Aklavik,** Fort Simpson, Haines Junction and **Kuujuaq.** Experimental work at these stations included the testing of field and greenhouse crops under northern conditions, variety trials of numerous cereal , forage and vegetable crops and improvement of cultivating practices **(Nowasad,** 1958; **Gilbey,** 1954; Abbott, **1954;** Harris **et al, 1972; Hamilton, 1958).** In addition to the research farms, a large number of market gardens, private farms and local gardens were successfully supplying produce to surrounding population **centres.**

The efforts of these various projects demonstrated the horticultural and technical feasibility of northern crop production **and establ**ished a database upon which future projects could build.

In the late 1960's, Agriculture Canada decided to phase out the northern experimental stations as part of a departmental **pol**icy to discontinue marginal agriculture and devote resources to improving existing agriculture in established areas.

In the past decade, rapidly escalating prices for imported produce have prompted a return to local agricultural practices and the re-establishment of market gardening in numerous northern **centres.** At present, **Dawson** City alone can boast 3 **commercial** gardens, some 50 domestic gardens and over 50 greenhouses which Produce vegetables for local sale and distribution to other **centres** including Whitehorse and **Inuvik (McCracken** and Revel, 1982).

Until recently however, most attempts at agricultural development and research have been limited to regions at or below the Latitudinal tree line and along river valleys where soil and climatic conditions are most favourable for conventional crop production (Albright, 1933). In tundra regions the exposure to and demand for southern vegetables was, until recently, non-existent since native residents relied solely on country food resources to supply their diets. Agricultural activities first appeared in the form of small *kitchen gardens" constructed by local missionaries as a means of supplementing their predominantly meat diets (Dickson, 1947).

With the improvement of air services into communities and the increased awareness and utilization of imported foodstuffs, the demand for fresh vegetables was markedly increased. However, the overall quality, variety and availability of imported produce was generally poorer and prices much higher than for the same items in southern centres.

In the 1970's a number of government-supported projects were launched in arctic communities to evaluate technical and economic aspects of local vegetable production in conventional greenhouses. The two most significant projects, carried out in Sanikiluaq and Frobisher Bay during 1976, examined cucumber, tomato and salad green production (Williams, 1976; Webb, 1976; Campbell, 1976). These projects were short-lived, terminating after the first season and created the general impression that agriculture above the tree line was unfeasible and not deserving of further study.

The failure of these projects may have resulted from a number of factors;

-lack of experience on the part of the operators
-high capital costs
-limited utilization of local resources
-unsuitable or failure-prone technology
-lack of community involvement or participation
-lack of a research/development plan

1-2-2 RANKIN INLET : 1979 - 1983

In 1979, The University of Toronto, with the support of the Dormer Canadian Foundation, initiated a 5-year research program into Arctic crop production. Facilities were constructed in Rankin Inlet and at Alexandra Fiord, Ellesmere Island. Research was directed towards *small-scale seasonal cultivation* of crops with heavy emphasis on utilization of local resources and the implementation of inexpensive techniques to improve growing conditions (Cummins *et al*, 1987; Romer, 1983; Bergsma, 1986). A wide range of temperate crops and selected edible tundra species were grown during the summer months in solar-heated (passive) insulated cold frames and lightweight domes (Photo 1 and 2). Soil mixtures were prepared using local sand, organic peat and lake sediment deposits. The studies clearly demonstrated that:

- A wide variety of vegetables including potatoes, lettuce, spinach, chinese cabbage, turnips, radishes and beets could be grown economically in small-scale cold frame gardens during the short growing season.

  Local soil resources could be utilized to provide an effective growth medium for vegetable cultivation.

  Several species of indigenous tundra plants including Dandelion (*Taraxacum lacerum*) and Mountain Sorrel (*Oxyria digyna*) demonstrated potential for use as northern cultivars.

  Growing conditions could be easily improved using simple and cost-effective ameliorative techniques which reduced heat loss and extended the growing season.

  Sufficient local interest was generated to ensure acceptance by the community and its participation in future projects.

The University of Toronto research provided the framework for the development of an arctic crop production program, but many questions remain to be answered before northern greenhousing and market gardening can become a reality.

1. Is it horticulturally feasible to extend vegetable production into the fall, winter and spring seasons?
2. What modifications to existing southern greenhouses would be required to attain this goal?
3. What are the operating costs of northern production and is local production economically beneficial ?
4. What are the current levels of vegetable consumption in northern communities and what scale of project would realistically be required to meet these demands?

PHOTO 1 : The University of Toronto "**Keewatin** Gardens" research facility in **Rankin** Inlet, **NWT.** 1982. Insulated cold frames fitted with polyethylene covers are seen in the foreground and fabrene dome in the background.

PHOTO 2 : The **Keewatin** Gardens in **Rankin** Inlet, **NWT.** 1982. Visitors examining southern vegetables on display in insulated cold frames with covers removed.

1-2-3 POND INLET : 1985 -1986

Two projects were commissioned by the Dept. of Economic Development in 1986. The first involved a marketing study which evaluated the current levels of vegetable consumption and estimated the potential market for local greenhouse production in 5 major northern centres (Nichols Applied Management, 1986).
The second and present study involved the design, construction and operation of a greenhouse in Pond Inlet, NWT in order to examine some of the technical, horticultural and economic aspects of northern vegetable production. The project was executed in 3 phases) summarized as follows:

PHASE ONE (June-July 1985)

With a grant from the Dept. of Indian Affairs and Northern Development and with logistic support from the Toonoonik-Sahoonik Co-op, the preliminary construction phase of the Pond Inlet Gardens was completed. The cedar frame and acrylic glazing of the prototype solar greenhouse were assembled on a temporary pad in Pond Inlet (Photo 3). In addition, several cold frames were constructed and empty oil drums to be used as container gardens were cut in half. Two fabrene domes, supplied courtesy of the University of Toronto, were also included in the facility. Details concerning this initial stage are presented in Poole, 1985, ‘Polar Solar: Report on the design, construction and installation of a greenhouse at Pond Inlet, NWT".

PHASE TWO (Oct-Nov 1985)

In the fall of 1985, subsequent suPport from the DIAND and T.S. Co-op resulted in the upgrading of the greenhouse structure to permit evaluation” of vegetable production on a year-round basis. The greenhouse was relocated to a position adjacent to the T.S. Co-op’s newly-constructed Sauniq Hotel (Photo 4). Changes included the installation of a heat storage foundation and solar collector (completed in 1986) for passive solar heat capture and storage, hydroponic beds, as well as protective insulation, lighting and heating systems for wintertime operation.

PHASE THREE (Hay-Dee 1986)

In the spring of 1986, operation of the greenhouse was initiated under a grant from the EDA directorate (GNWT) and under the supervision of the Dept. of Economic Development. Soil and hydroponic systems were utilized in the greenhouse to assess the economic feasibility of vegetable production. In addition, the outdoor cultivation of vegetables in cold-frame container gardens was examined. A horticultural trainee was engaged and instructed in the operation of the greenhouse and gardens. The results and recommendations of this phase are presented in this report.

PHOTO 3 : The Pond Inlet Gardens facility following completion of Phase 1. July, 1985.

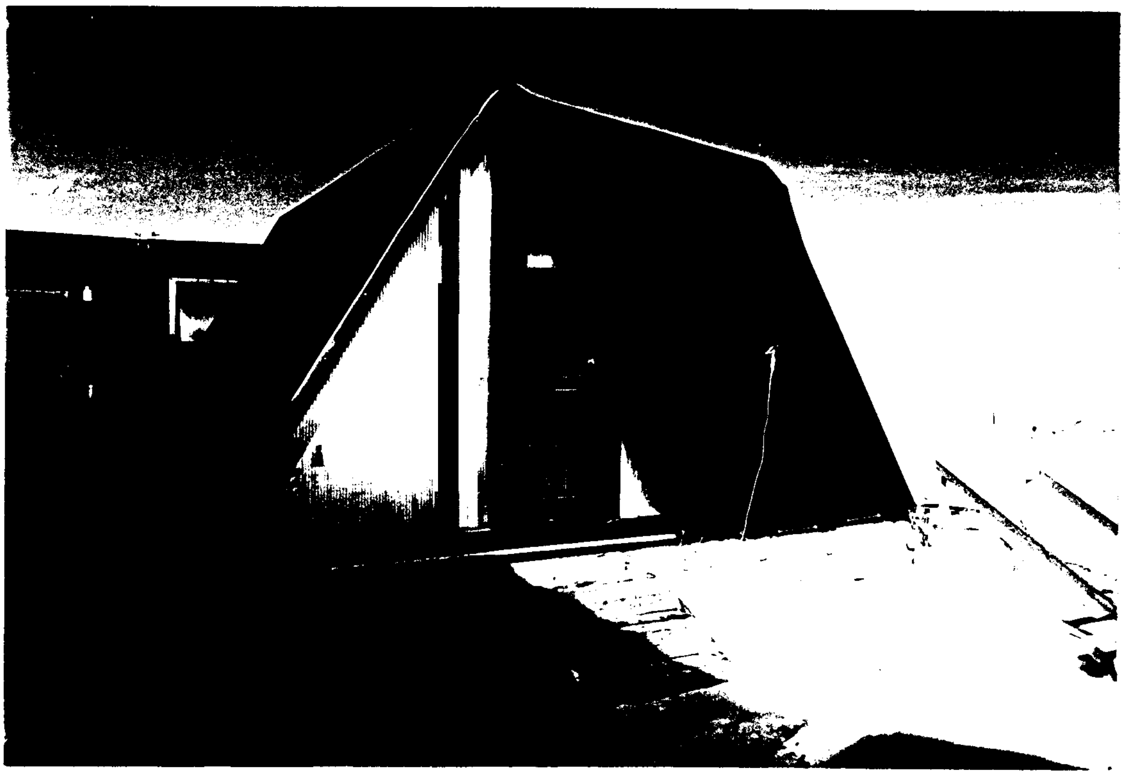


PHOTO 4 : The relocated greenhouse structure following the completion of construction Phase 2. May, 1986. Greenhouse is mounted on heat storage foundation and is fitted with canvas cover and insulation.

1-3 OBJECTIVES

GENERAL OBJECTIVE:

To examine the horticultural, technical and economic feasibility of arctic vegetable production in all seasons.

SPECIFIC OBJECTIVES :

a) Technical Aspects

- To monitor climatic conditions and assess greenhouse performance during summer, fall and winter growing seasons (temperatures, sunlight, humidity).
- To evaluate effectiveness of climate control and energy conservation systems (insulation, thermostats, fans) .
- To test performance of solar heat capture and storage systems incorporated into the greenhouse design.
- To report on the energy inputs and operational requirements for each season.
- To recommend changes to the existing design for future projects.

b) Horticultural Aspects

- To monitor the performance and quantify productivity of different vegetable varieties grown in greenhouse and outdoor cold frame conditions.
- To compare the performance and productivity of vegetables grown in soil versus hydroponic culture.
- To evaluate the suitability of local soil resources for vegetable production.
- To determine the feasibility of vegetable production in each of the four seasons.
- To recommend successful plant varieties and horticultural systems for use in future projects.

c) Economic Aspects

- To determine greenhouse operating costs with respect to energy, materials and **labour** an all seasons.

- To quantify seasonal variance in production costs for vegetable varieties tested in 1986.

To provide a cost assessment of local production and evaluate whether northern vegetables can be sold at prices competitive to imports.

To identify factors regulating prices of imported produce and determine their effect on the **feasibility** of future development projects.

d) **Community** Aspects

To train a local resident in all aspects of greenhouse operation and crop production.

To assess community acceptance of local agricultural projects and encourage **public** awareness and participation in the current project.

SECTION 2: DESCRIPTION OF GREENHOUSE STRUCTURE AND SYSTEMS

In this section the greenhouse structure, climate control systems and vegetable production facilities which comprise the Pond Inlet Gardens will be individually described and illustrated. More specific details concerning equipment and materials utilized (brand names and suppliers) may be found in : 'Pond Inlet Gardens Operations Manual", Romer, 1987.

2-1 BASIC STRUCTURE

2-f-l LOCATION

The Pond Inlet greenhouse is a free-standing structure with an A-frame design consisting of 3 distinct sections mounted on top of each other. These are the (1) heat storage foundation, (2) cedar frame and glazing and (3) solar collector panel (Photo 5).
The greenhouse is constructed on a compacted pad of gravel and sand adjacent to the northeast corner of the Sauniq Hotel . The south and west facing walls of the greenhouse stand 2 and 3 meters away, respectively, from the hotel walls. A small utility corridor (40 x 40 cm) providing electricity, water and heated glycol extends between the hotel kitchen and the west wall of the greenhouse.

2-1-2 HEAT STORAGE FOUNDATION

The greenhouse frame is constructed on top of an insulated heat storage foundation with external dimensions measuring 4.'88 x 4.88 x 1.22 meters (length, width, height) (Photo 5, Figure 1). The design is based on an underground heat storage system developed and tested by the Brace Research Institute (Brace Research Institute, 1984; Coffin and Alward, 1985) in Ste. Anne de Bellvue, P.Q.. Air is utilized as the heat transfer medium and fine sand as the storage mass. To reduce heat loss and improve storage capacity, insulated walls were added to the basic design and the entire structure was built above the permafrost layer on a pad of crushed gravel.

PHOTO 6 : **Installation** of corrugated plastic drainage **tubing** into heat storage foundation, November **1985.**

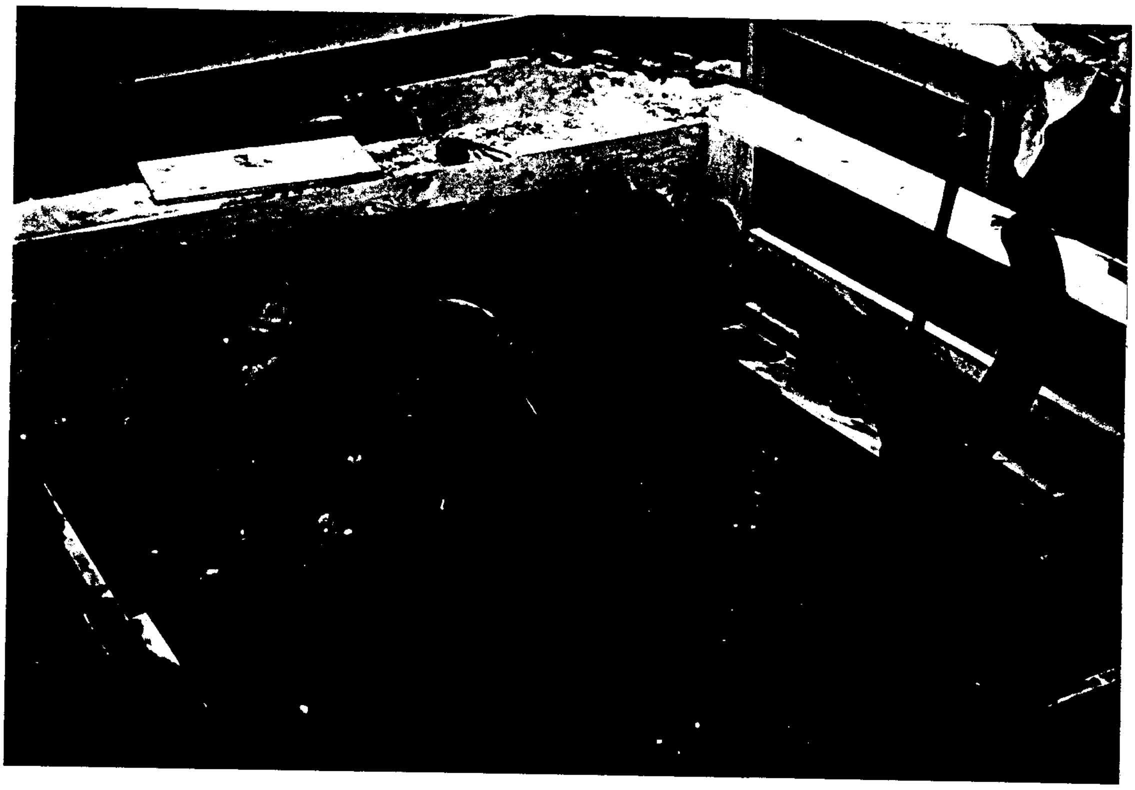
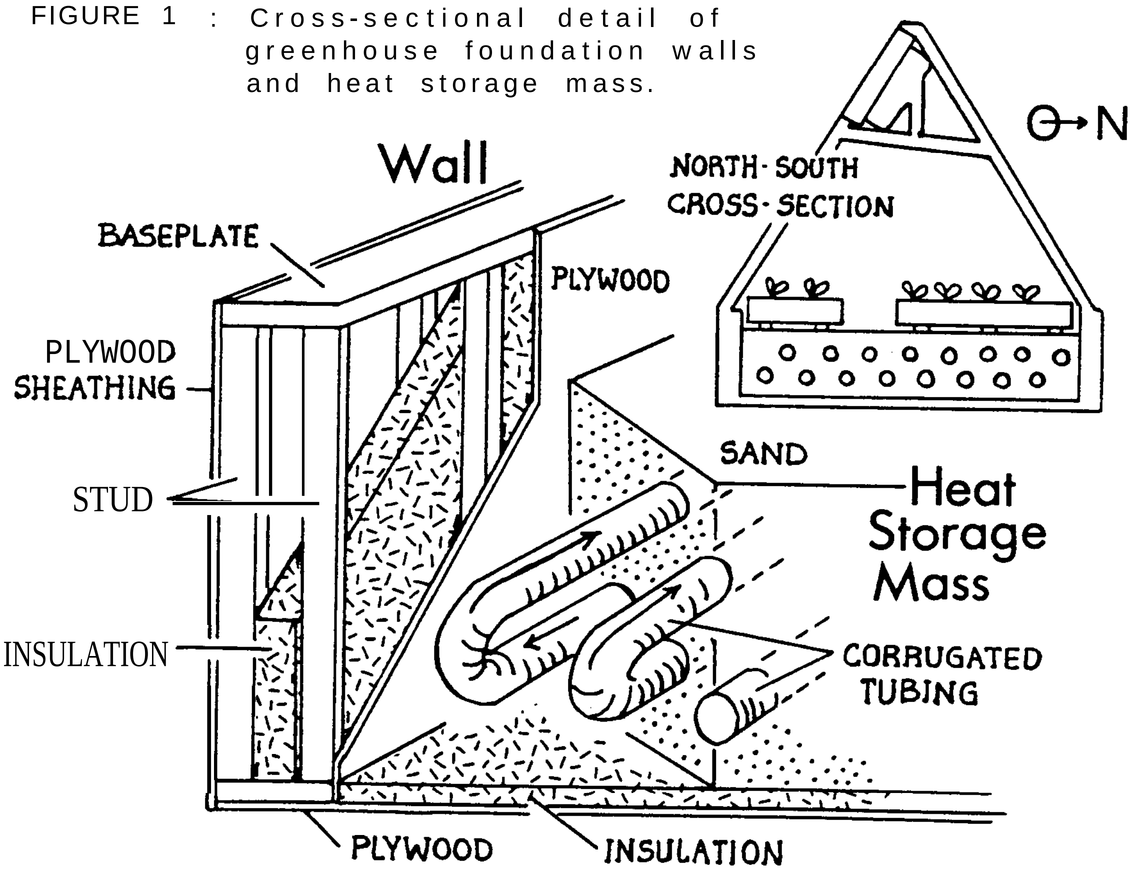


FIGURE 1 : Cross-sectional detail of greenhouse foundation walls and heat storage mass.



[A] Foundation

The walls of the foundation measure 25.4 cm in thickness and **consist** of a rigid **styrofoam** core (extruded polystyrene 11.4 cm) sandwiched between two air spaces and plywood sheathing (19 nun). The walls are reinforced with 38 x 64 **mm** studs at 61 cm centers on both sides of the insulation. The greenhouse frame is anchored by means of lag screws to a baseplate (38 x 235 nun) which runs around the perimeter of the wall. The foundation floor lies directly on top of the gravel pad and consists of a base of plywood sheathing covered by a layer of extruded polystyrene insulation (51 nun).

[B] Heat Storage Mass

The interior of the foundation is filled to a depth of 91 cm with fine sand which forms the heat storage mass. Sand was chosen as the storage medium for two principal reasons :

1. It was more readily available in Pond **Inlet** than crushed stone or rocks when the foundation was constructed in **Oct-Nov** 1985.

2. The Brace design has demonstrated that sand provides an effective short term heat storage medium which will store heat over 1-2 days and also contribute to the dehumidification of the greenhouse air.

A series of 8 plastic corrugated drainage tubes (102 **mm** diameter) are evenly distributed throughout the storage medium and originate from upper and lower header boxes in the west wall of the greenhouse (Photo 6).

[C] Function

Heated air is delivered to the foundation from the solar collector via a 6-inch sheet metal duct (Figure 4). Once in the lower header box, the air is distributed and passes through the 8 tubes. As it travels through the tubing, heat is transferred from the air into the surrounding sand, thus heating or ‘charging” the storage mass. The cooled air is returned to the greenhouse through the upper header box. The stored heat is released into the greenhouse by (a) natural convection and (b) radiation from the soil surface. In addition, cool air may be circulated through the heated mass to increase speed of energy release.

2-1-3 CEDAR FRAME AND GLAZING

The greenhouse frame is constructed from 89 x 89 mm western red cedar with acrylic glazing on all 4 sides (Photo 5). In Pond Inlet and other areas above 60°N, the relatively low solar angle (which reaches a maximum of 43° at the summer solstice) reduces the need for a glazed roof. Instead, the frame supports an insulated roof which is made up of a layer of polystyrene insulation (38 mm) sandwiched between two layers of plywood sheathing (11 mm). The use of an insulated roof is expected to decrease heat loss and improve microclimate within the greenhouse.

The north and south facing walls are identically inclined at 60° while the east and west facing gable end walls are vertical. The greenhouse is entered through a doorway in the east wall and is ventilated by means of two fanlights (vents) mounted at a height of 2 m in the end walls.

The greenhouse is glazed with SDP acrylic (Acrylite tm) panels which consist of two layers of glazing separated by an insulating air space of 11 mm (Figure 2). The panels are flexible and will expand and contract with temperature changes (1 cm over 50°C). To accommodate for the continuous expansion and contraction, the panels are held in place on the frame by means of a sill gasket and cedar cap assembly which were designed for this greenhouse to effectively replace the more costly commercially-available metal fittings.

Acrylic glazing was selected for several reasons:

(1) High light transmission - 83% of incident light striking the exterior is transmitted through the glazing into the greenhouse.

(2) Strength - The ribbed panels are highly resistant to shocks once mounted in the frame. In addition, the panels will puncture instead of shattering which permits easy and rapid repair.

(3) Durability - Acrylite panels have an expected life of 20 years with good resistance to discoloration and degradation by UV radiation.

(4) Weight - Acrylic is considerably less expensive and less fragile for shipping than plate glass or conventional glazings due to its light weight.

PHOTO 5 : The **completed** Pond Inlet Gardens greenhouse, **August** 1986

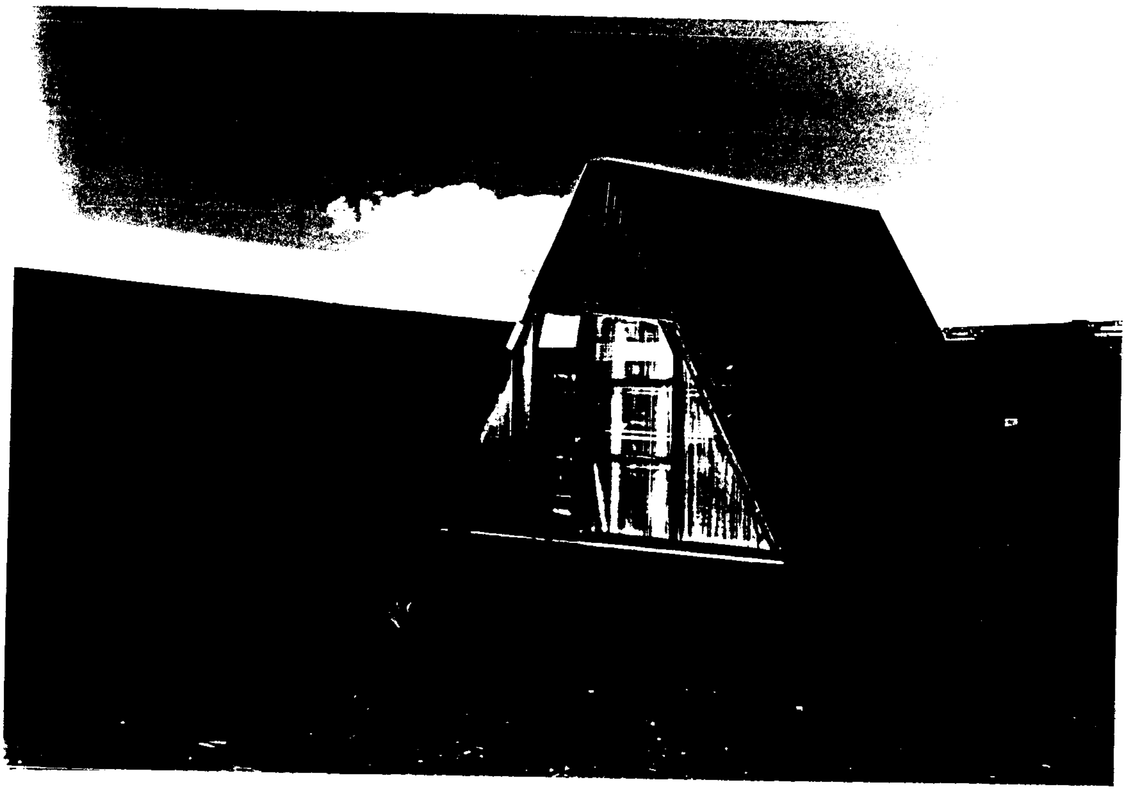
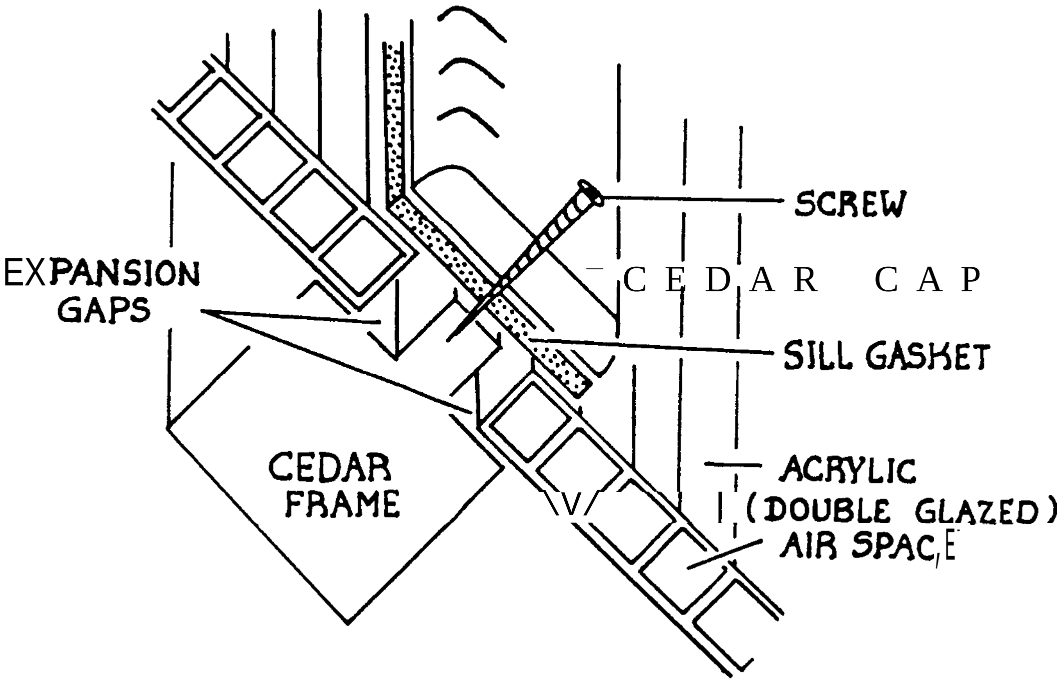


FIGURE 2 : Cross-sectional detail of acrylic glazing and cedar cap assembly.



2-1-4 SOLAR COLLECTOR

The greenhouse is fitted with an ‘absorption plate" solar collector which is mounted on top of the insulated roof (Photo 7). The collector panel (4.88 x 1.52 m) is oriented along the east-west axis of the greenhouse facing south and has an effective absorption area of 7.44 m2. A cross-sectional detail of the panel construction is illustrated in Figure 3.

[A] Structure

The exterior of the collector consists of SOP acrylic panels (11 mm) above a 25 mm sealed air space which both act as insulating layers between the exterior and the black sheet metal absorbing plate. The plate absorbs solar radiation and heats the air corridor situated directly behind it. The heated air corridor (25 mm) is connected into the greenhouse at one end of the panel and to the heat storage mass at the other by means of sheet metal ducting. The corridor is insulated with 25 mm Thermax insulation panels mounted on a support wall of 11 mm plywood sheathing and 38 x 89 mm studs. The temperature in the heated air corridor is measured by a remote sensing probe attached to a thermostat in the greenhouse.

[B] Function

The collector panel functions by absorbing solar radiation on the black plate thereby causing the air corridor to heat up. When the desired set point temperature is attained (40-60°C), the thermostat in the air corridor activates the collector fan which forces the heated air out of the panels and down into the heat storage foundation (Fig. 4). The heated air in the corridor is replaced with cooler air from inside the greenhouse and the fan stops.

Between the months of May and August 1986, the heat storage system operated without the benefit of the solar collector which was not completed until the end of August. During this time the collector fan was mounted directly on top of the 6" sheet metal ducting (Fig. 4) to funnel hot air from the upper half of the greenhouse down into the heat storage foundation.

PHOTO 7 : South face of greenhouse with solar collector panel displayed.

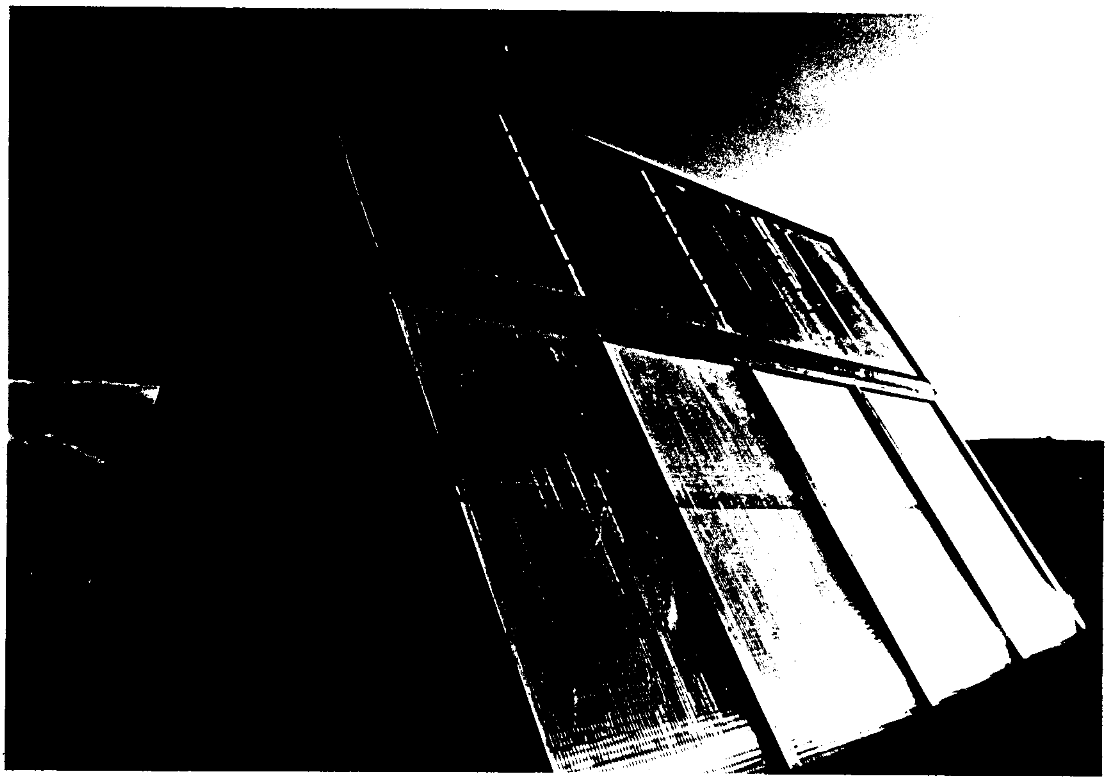


FIGURE 3 : Cross-sectional detail of solar collector panel.

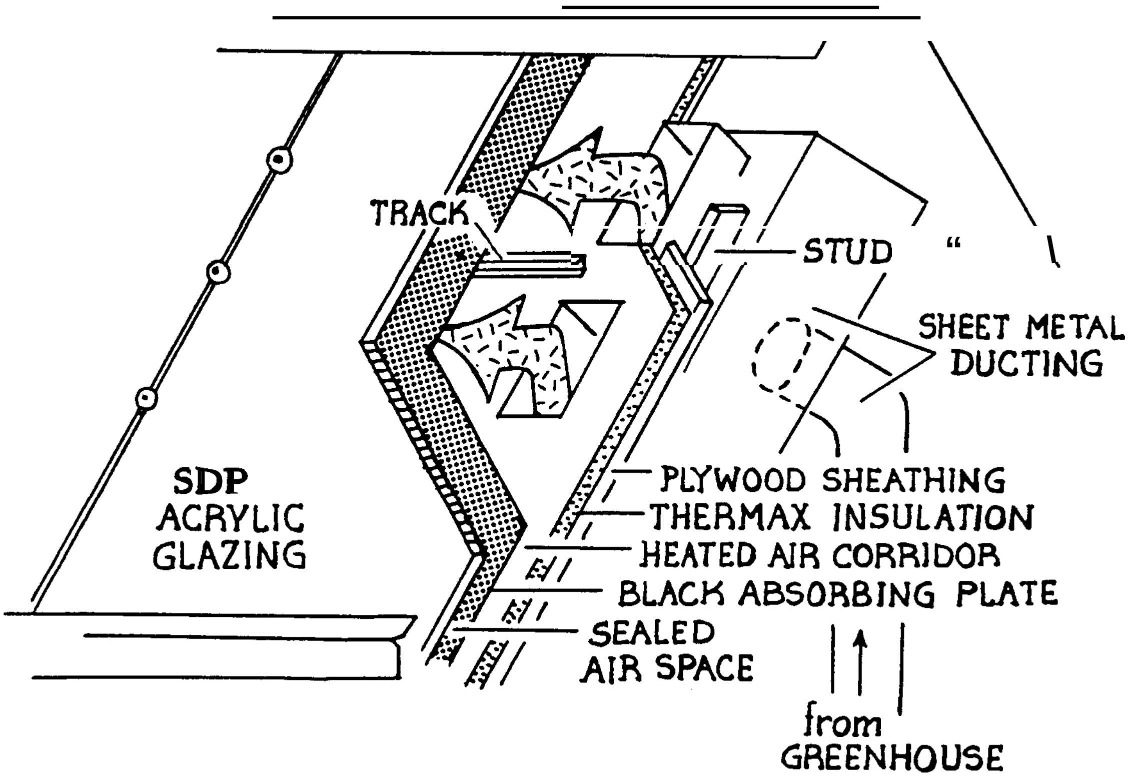
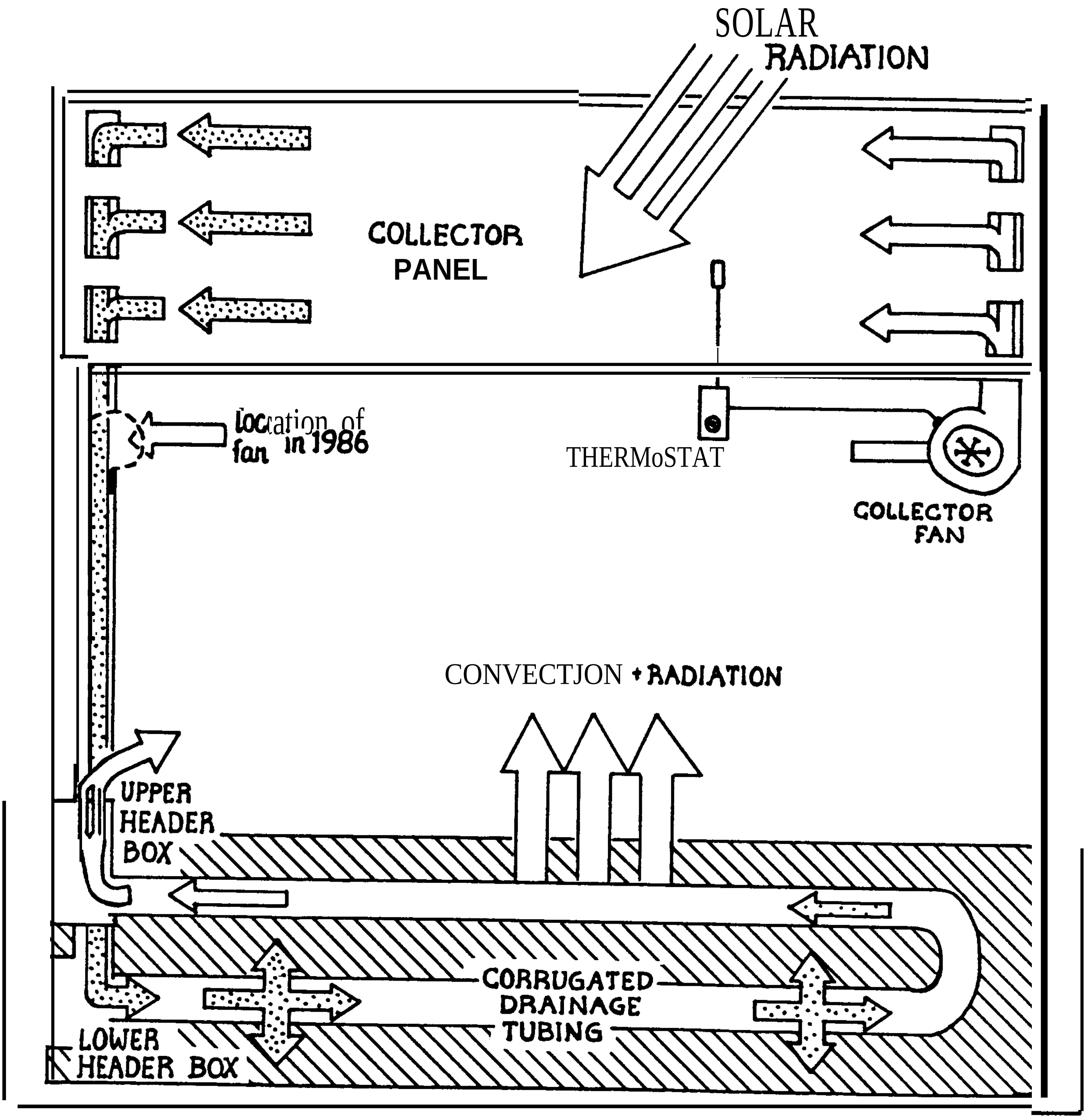


FIGURE 4 : Diagrammatic representation of heat absorption and transfer in the solar collector panel and storage foundation.



2-2 UTILITIES

2-2-1 HEATING SYSTEM

During the spring and summer months, solar radiation represents the primary heat source for the greenhouse. In order to permit operation during the fall and winter, the greenhouse is equipped with a Horizontal Unit Heater which consists of a glycol radiator and a thermostatically-controlled blower fan (Photo 8). Heated glycol (from 40°C-70°C depending on season) originates from the hotel's boiler system and is shunted into the greenhouse via an insulated utility corridor.

2-2-2 COOLING AND VENTILATION

In the summer the greenhouse is equipped to be ventilated in 2 ways. A passive flow of air occurs between the vents in the east and west end walls. In addition, a single speed shutter exhaust fan is mounted in the vent above the doorway of the east wall (Photo 9). This thermostatically-controlled fan removes heated air when indoor temperatures reach unfavorably high levels to assist in proper air circulation and greenhouse ventilation.
In the fall and winter months, a slow speed bathroom fan is mounted in the peak of the greenhouse to circulate the indoor air. At present, no system has been installed to effect proper air exchange in the winterized greenhouse. Ventilation occurs solely via air leakage through the doorway and frame perimeter.

2-2-3 LIGHTING SYSTEMS

[a] Metal Halide LamP

The greenhouse is equipped with a 1000W metal halide grow lamp and ballast which provides supplementary lighting for plants during the fall and complete lighting during the winter months. The lamp is mounted in the center of the greenhouse roof 1.8 m directly above the NFT hydroponic bed and 3.3 m away from the corners of the greenhouse frame. Its operation is controlled by means of a grounded program timer mounted in the main electrical panel (Photo 8).

[B] Fluorescent Bulbs

Two sets of fluorescent light fixtures (4 x 40 Watts each) are mounted on the seedling racks located by the east wall of t-he greenhouse (Photo 9). Vitalite tm (by Duralite) grow bulbs were installed to provide seedlings with the full spectrum of light required for optimal growth. These lights were also controlled by means of a grounded program timer.

2-2-4 ELECTRICAL SYSTEM AND WATER SUPPLY

The greenhouse has a 60 amp current entry line terminating in a junction box mounted on the main electrical panel shown in Photo 8. The breaker panel supplies all the greenhouse fans, lights and pumps. Elapsed time hourmeters connected to all 3 fans record their hours of operation, and operating hours of lights and pumps are obtained from the settings of the program timers to determine power consumption.
A cold water line originating in the hotel pantry is mounted on the support base of the electrical panel to supply the greenhouse water requirements. Water and power lines pass into the greenhouse through an insulated utility corridor connecting the hotel and greenhouse west wall.

2-2-5 WINTERIZATION SYSTEMS

Two systems were designed to reduce heat loss and permit operation of the greenhouse throughout the winter :

[1] Inside the greenhouse, insulative panels 10 cm in thickness are installed in the fall to form a friction fit between the foundation baseplate and greenhouse ceiling (Photo 10). The insulation used was THERMAX brand Celotex sheathing, a glass-fiber-reinforced polyisocyanurate foamboard with reflective aluminum foil faces (RSI=4.93). The individual panels are not moveable and must be stored outside the greenhouse for the summer months.

[2] The exterior of the winterized greenhouse is fitted with a heavy black canvas cover which provides protection for the glazing (Photo 11). The south facing wall of the cover is equipped with zippered flaps to allow exposure of the solar collector and/or greenhouse glazing to the sun in early springtime. The cover is held in place by means of polypropylene rope passed through hitching rings mounted in the foundation wall.

[3] A small airlock, constructed from 38 x 64 mm studs and a canvas cover, is attached to the greenhouse doorway. The winterized greenhouse is equipped with heating and lighting systems described in Section 2-2-~ and 2-2-3.

PHOTO 8 : Interior view of greenhouse west wall showing gravel hydroponic beds, horizontal unit heater, electrical panel and water line.

PHOTO 9 : Interior view of greenhouse east wall with NFT hydroponic bed in foreground. Also visible are seedling racks and neon fixtures; collector and exhaust fans; doorway and entrance.

PHOTO 10 : Interior view of winterized greenhouse with insulating panels. November, 1986.

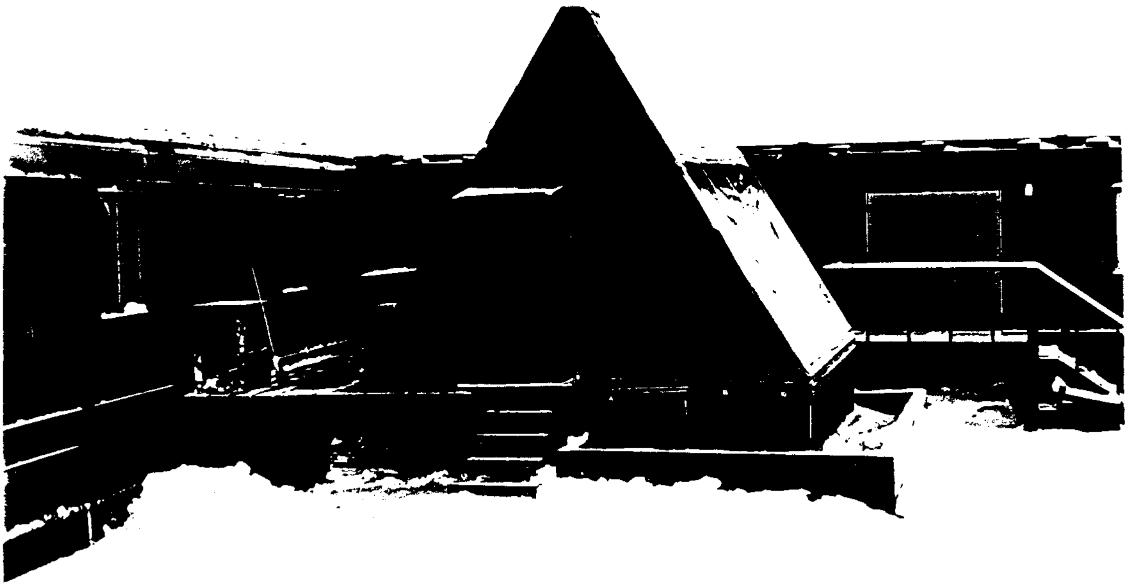


PHOTO 11 : Exterior view of winterized greenhouse with black canvas cover and airlock installed. November, 1986.

2-3 GROWING FACILITIES

Conventional soil beds and hydroponic growth systems were tested in the Pond Inlet greenhouse in 1986. For the latter, both water and gravel culture techniques were used.

2-3-1 NFT HYDROPONIC BED

NFT or Nutrient Film Technique is a relatively recent method of hydroponic water culture which uses no substrate (i.e. gravel, sand or other medium). Instead, plants are grown with their roots in a shallow stream of recirculated water in which all necessary nutrients have been dissolved (Cooper, 1979; Resh, 1985). Plants develop a thick root mat which grows partly below the nutrient stream in the gutter and partly above it to ensure that roots receive an adequate supply of water, nutrients and oxygen.

The system consists of 8 growth troughs (gutters) which are supported at a slight slope (1" in 25") on a wooden frame (Figure 5). An 80 litre reservoir is located below the catchment end of the gutters. Nutrient solution from the reservoir enters the submersible pump (Little Giant P-AAA 360 l/min) and is pumped through a supply tube (12 mm) which dispenses it equally into the heads of the 8 gutters. The nutrient solution then flows down over the roots of the plants positioned at 15cm intervals along the gutters. The nutrient emerges from the gutters and is funnelled by the two catchment gutters back to the reservoir. An aquarium particle filter removes debris from the solution. The entire system (gutters, tubes and reservoir) is covered with black 4mm polyethylene to prevent growth of algae, eliminate light from the plant roots and reduce evaporative water loss from the system.

2-3-2 GRAVEL HYDROPONIC BEDS

The use of gravel culture is widespread in commercial hydroponic operations around the world. This method uses gravel as a sterile substrate in which growing plants are supported. Plant roots are fed by a nutrient solution flushed through the substrate at regular intervals (sub-irrigation system) . Nutrients may also be delivered through a series of thin ‘spaghetti” tubes or a perforated ooze hose system to supply a continuous flow of nutrients past the plant roots (Resh, 1985). The ooze hose system was chosen for testing in the Pond Inlet greenhouse because of its easier and more economical installation.

FIGURE 5: Structural diagram of NFT hydroponic bed including detail of seedling support system and plastic cover assembly.

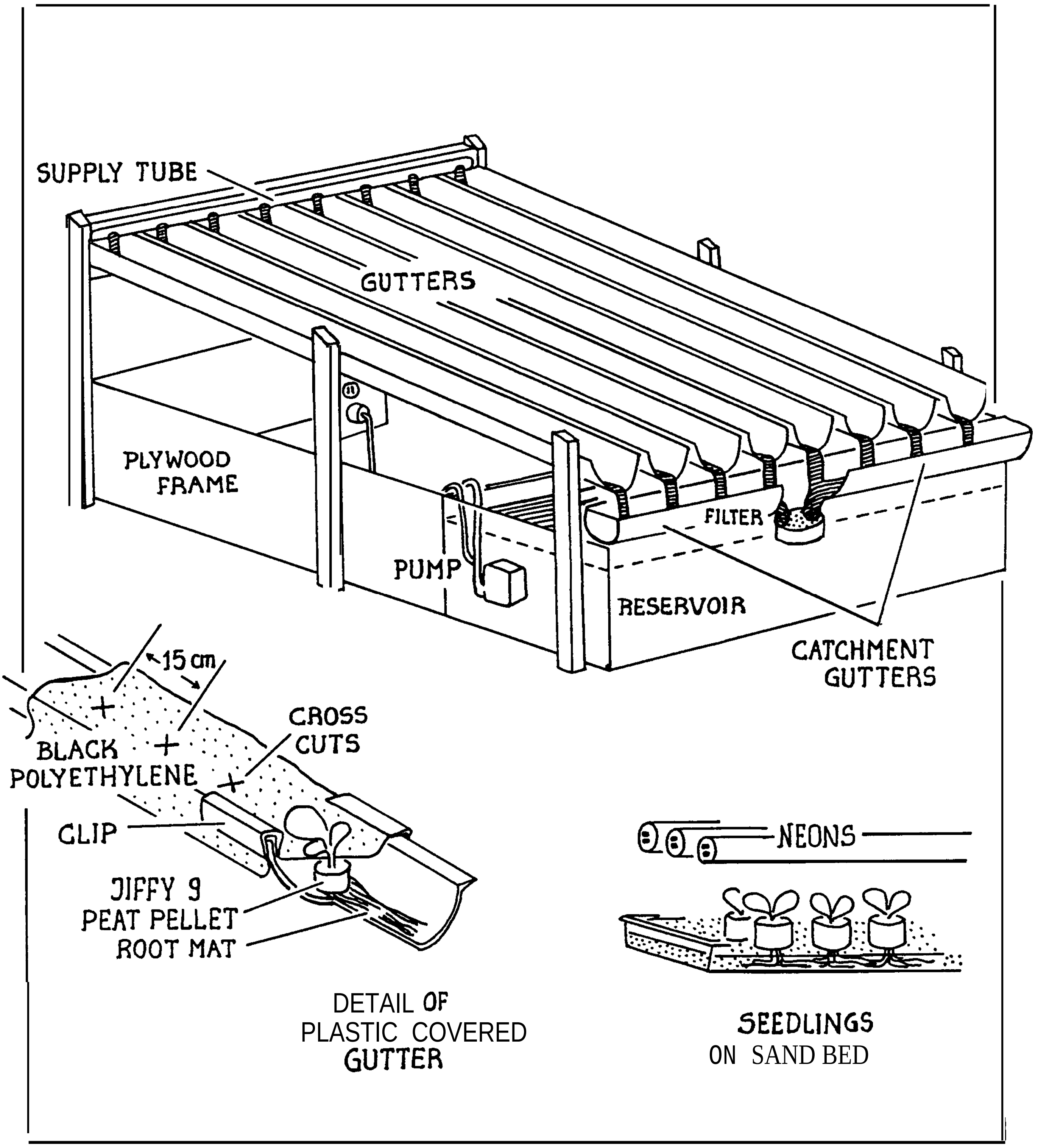
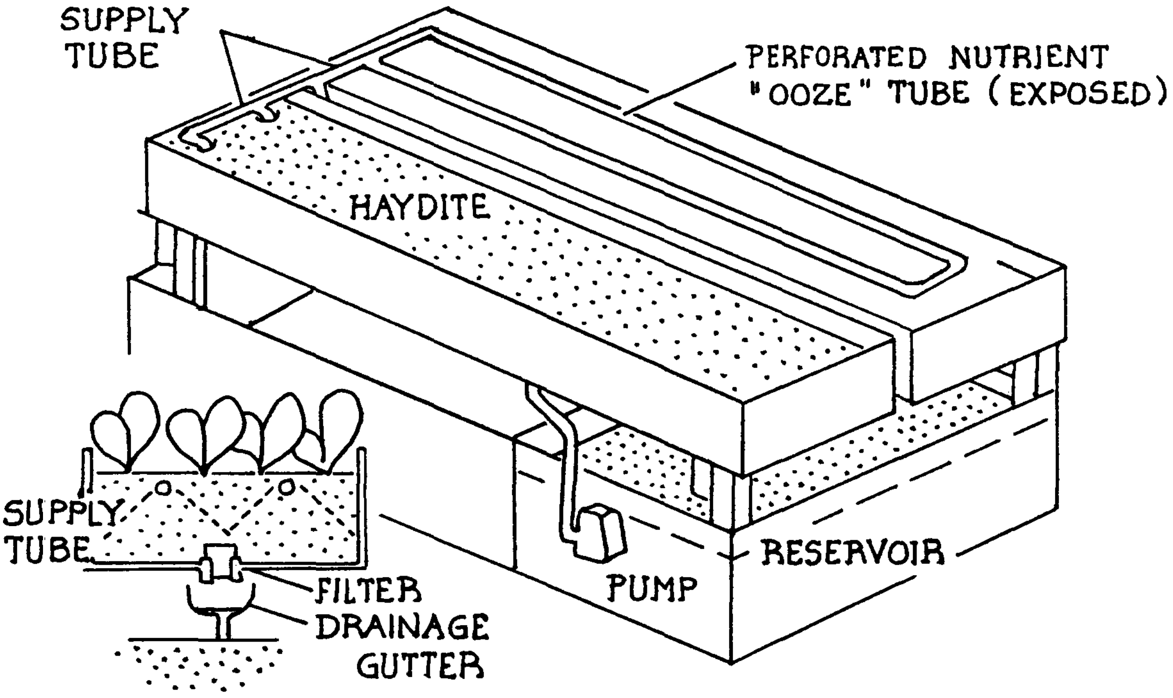


FIGURE 6 : Structural diagram and cross-sectional detail of the gravel culture hydroponic beds.



The system is composed of two beds each measuring 61 cm x 244 cm x 15.2 cm (width, length, depth) mounted on a supporting frame beneath which an 80 **litre** reservoir is situated (Figure 6, Photo 8). The beds are filled to a depth of **15** cm *with an* imported aggregate, **Haydite** (tin), a fired shale crushed into small particles between 3 and 6 **mm** in size. **Haydite** is very porous and is particularly suited to a spaghetti and/or ooze hose feeding system because its capillary action moves the nutrient solution laterally around the plant root systems **(Resh,** 1985).

K Nutrient solution from the reservoir enters the submersible pump (Little Giant **P-AAA** 360 l/rein) and flows through a 'supply tube **(12mm)** which dispenses it evenly into 4 perforated **"ooze"** tubes **(6mm). The nutrient trickles out** of the perforations in the tube and flows past the plant roots before returning to the reservoir via the catchment gutter located under the bed. An aquarium particle filter is used to prevent any debris from reaching the reservoir and clogging the pump and feeder **lines.** The nutrient is
K continuously ci**rculated** through the **tubing** without interruption.

2-3-3 SOIL BEDS

A total of 4 soil beds of different sizes are present inside the greenhouse (Photos 8, 9, 15, and 16). They are constructed from 11mm plywood sheathing and are raised above the sand foundation on 10 x 10cm beams. The measurements of the individual beds are as follows :

1 x [61 cm x 244 cm x 15 cm deep]
2 x [122 cm x 122 cm x 30 cm deep]
1 x [91 cm x 122 cm x 30 cm deep]

In addition, a number of smaller wooden boxes and hanging planters were utilized wherever additional space and light were available.

[A] Soil Mixture

All soil beds were filled in 1986 with a mixture of local soil components (not imported) found readily in the vicinity of the community. Fine sand was collected from the edges of lakes and raised beach areas and mixed in equal volume with partly decomposed organic peat dug from stream borders and disturbed areas. The soil components were sifted through a 6 mm screen mesh to remove large rocks and debris and to break up large clumps of material. No imported soil amendments (vermiculite etc) were added to the basic mixture. Fertilizer was applied to all beds and planters at regular 2-week intervals. A full description of growth procedures is found in Section 4-i.

2-3-4 OUTDOOR GROWING FACILITIES

A number of facilities exterior to the greenhouse were developed in 1985 and 1986 to expand the area available for summer cultivation and permit the growth of cool weather crops which are not as tolerant of the warm greenhouse conditions. The outdoor gardens were also situated adjacent to the Sauniq Hotel on it's gravel pad.

[A] Cold Frame Gardens

Three cold frames measuring 1.22 x 2.44 meters were constructed in 1985 following a design developed by the author for the Keewatin Gardens in Rankin Inlet (Photos 1 and 2) .

The frames consist of 14 mm plywood siding 30 cm in height supporting a polyethylene glazed A-frame and hinged door. The growth medium (soil) is separated from the gravel pad by a layer of plywood sheathing (6mm) and extruded polystyrene insulation (38mm). The soil mixture used in the cold frames during 1986 was the same as that of the greenhouse soil beds described in Section 2-3-3.
In trials conducted in Rankin Inlet, these simple structures effectively reduced wind activity and heat loss to the ground and raised ambient temperatures by an average of 10°C (Romer, 1983).

[B] Fabrene Domes

Two ‘igloo--shaped domes of 3 meters in diameter were provided by the University of Toronto from the Alexandra Fiord project (Ellesmere Island). The domes consist of a frame made of 8 fibreglass rods set into a plywood (30cm) base. The entire structure is glazed with Fabrene (tin), a tough, translucent material woven from polyolefin. Additional information concerning the thermal properties of these structures may be obtained from : Bergsma, 1986.

[C] 45 Gallon Drums

Empty oil drums were modified to grow potatoes. Drums were cut in half, painted matt black to absorb heat and filled with the same local soil mixture used in the greenhouse soil beds (Section 2-3-3). No glazing was designed or used for these containers.

SECTION 3: PERFORMANCE OF THE GREENHOUSE (CLIMATE AND CONTROL SYSTEMS)

This section is divided into four parts which examine a) the general climatic conditions which prevail in the Pond Inlet area; b) the growing conditions inside the greenhouse as recorded between May and November, 1986; c) the annual energy balance (heat loss versus gain) of the greenhouse; and d) the effectiveness of the individual systems (solar collector, heat storage foundation etc) at contributing to and maintaining a suitable growth climate.

3-1 GENERAL MACROCLIMATE

Before examining the performance of the greenhouse, it is important to describe the macroclimatic conditions which prevail for the Pond Inlet area and compare 1986 conditions to those of preceding years. The success of the greenhouse in future years may then be predicted relative to this year's performance. Climatic data presented in this section were obtained from the records of Atmospheric Environment Service (AES) weather station in Pond Inlet, NWT.

[A] Average Conditions

Temperature and sunlight are two of the most important factors governing plant growth and productivity in Arctic regions. In Pond Inlet, mean monthly temperatures (Table 1) remain below zero for all except 3 months of the year. The average frost-free period is around 70 days extending from mid-June to the end of August (Figure 7). The mean maximum temperatures do not exceed 10°C, a level considered to be a suitable minimum for growth of temperate vegetables. It is therefore clear that the successful production of crops in this area would require substantial temperature amelioration.

FIGURE 7 : Maximum and minimum temperature **means** (°C) recorded between 1975 and 1980 by Atmospheric **Environment** Service in Pond Inlet, **NWT.**

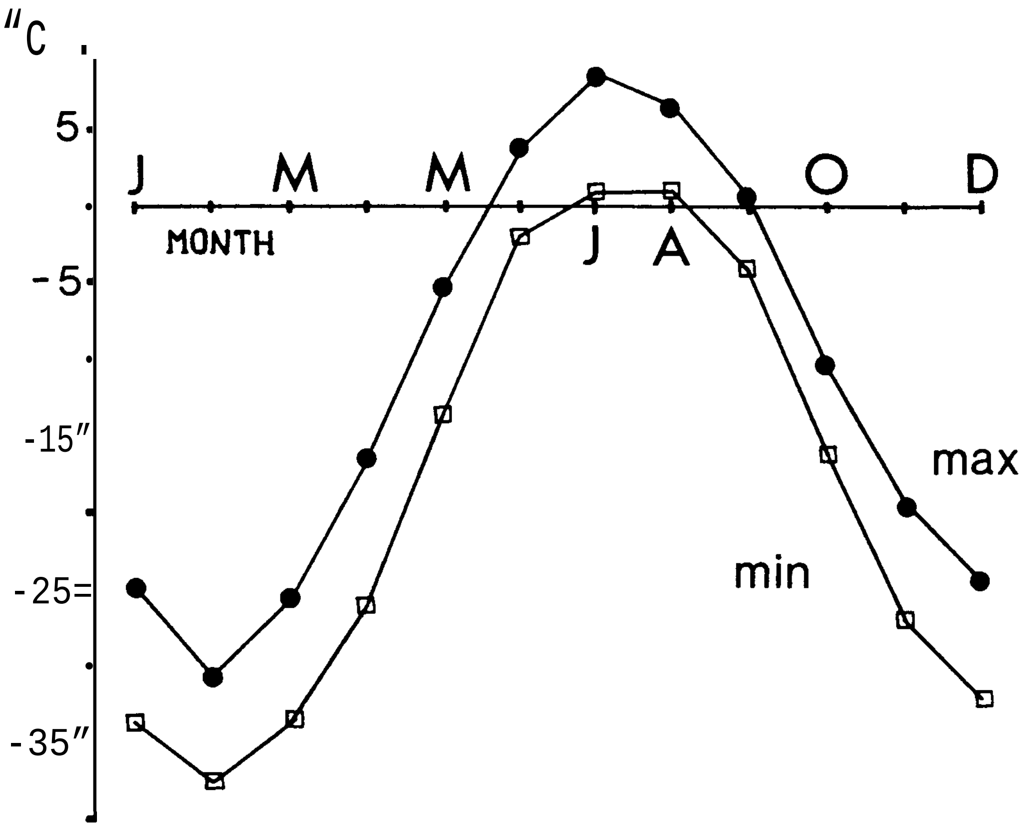


TABLE 1 : Monthly temperature means (°C) and plant degree days recorded by Atmospheric Environment Service in Pond Inlet, **NWT**

Mean Monthly Temperature	**JAN**	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
(1975-80)	**-29.1**	**-34.1**	**-29.7**	+1.8	-9.5	0.5	4.7	3.9	**-2.3**	**-13.5**	**-23.4**	**-28.7**
(1986)	–	–	–	–	-7.9	**-0.6**	4.1	3.6	-3.1	**-18.0**	**-28.7**	—
Difference °C					**+1.6**	-0.9	**-0.6**	**-0.3**	**-0.8**	**-4.5**	-5.3	

Plant Degree Days												
(1975-80)	**1298.9**	1313.1	**1317.4**	**1037.6**	**691.2**	**369.1**	**251.0**	**276.2**	**453.0**	815.3	**1086.1**	**1286.4**
(1986)	–	–	–	–	643.8	**402.1**	**269.6**	**286.4**	475.4	**954.2**	1244.7	—
Difference					47.4	+33.0	+18.6	+10.2	**+22.4**	**+138.9**	**+158.6**	

FIGURE 8 : Average daily **totals** of bright sunshine **hours** and daylight hours recorded **by AES,** POnd **Inlet.** (Comparison of 1986 versus 1983-85 means)

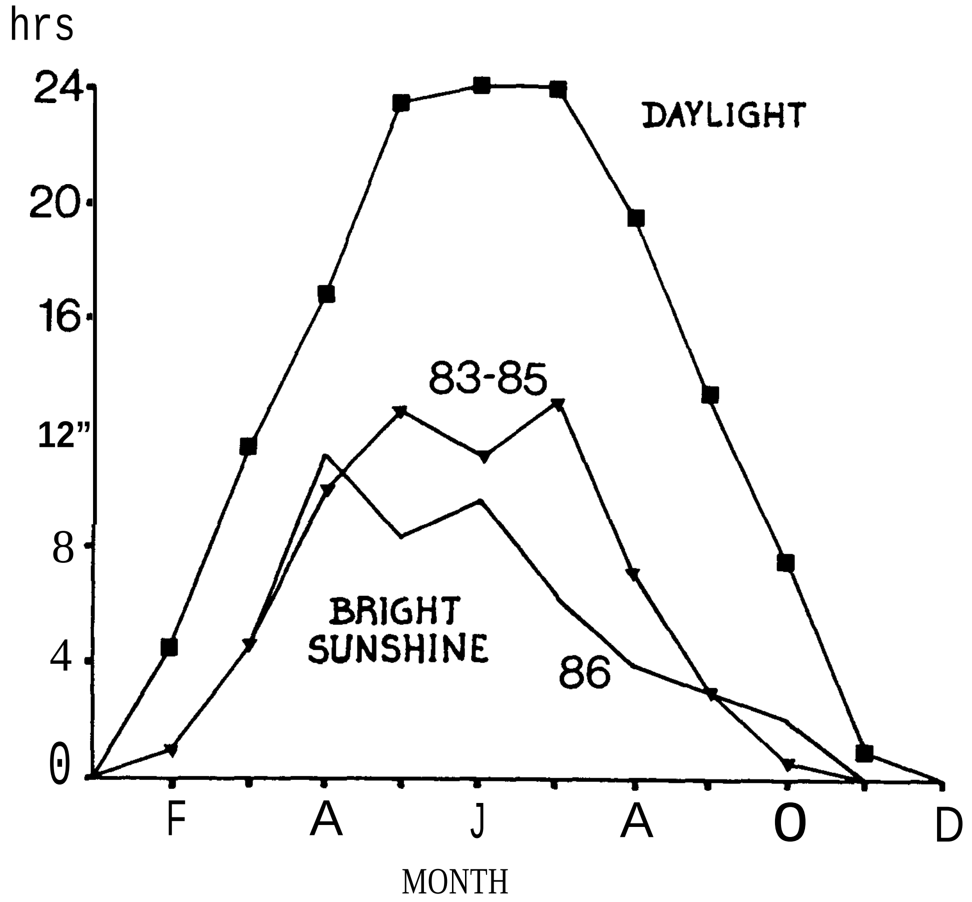


TABLE 2 : Monthly totals of bright sunshine hours and daylight hours recorded by **AES,** Pond Inlet. (Comparison of 1986 versus 1983-85 means)

	JAN	**FEB**	**MAR**	**APR**	**MAY**	**JUN**	**JUL**	**AUG**	**SEP**	**OCT**	**NOV**	**DEC**
Total Daylength Hours	0	125.6	**351.0**	501.8	**721.4**	720.0	744.0	**601.3**	**394.8**	241.8	**30.3**	0
Bright Sunshine Hours												
(1983-85)	**0**	49.8	151.1	**308.1**	**400.6**	338.9	413.0	**224.4**	88.6	21.0	0	0
(1986)	**0**	37.8	**147.7**	**338.3**	260.4	279.7	**196.7**	**123.8**	87.3	63.7	**10.2**	**0**

Sunlight represents the greatest energy input into the arctic environment and the successful capture and storage of this energy by the greenhouse makes the difference between success and failure in any given year. The total hours of daylight and average Bright Sunshine Hours (unobstructed skies) are presented in Figure 8 and Table 2. Between April and August, Pond Inlet benefits from extended daylength periods of 16-24 hrs. Continuous 24-hour days occur between May 9 and August 5 at this latitude. From April to July, bright sunlight is recorded an average of 10 to 12 hours per day.

[B] 1986 Conditions

The climate for the 1986 growing season was unfavorable in comparison to previous years. Mean monthly temperatures were consistently lower than the 5 year averages (Table 1). The only exception was in May when both temperatures and number of Bright Sunlight Hours were above average values. Temperature means for October and November showed the most dramatic differences, being 4.5 and 5.3°C lower respectively than average values.

The cooler climatic conditions are also reflected in the number of Plant Degree Days which increased 8.5X over the average value between the months of May and November (4276 vs 3942) (A PDD refers to the number of degrees per day that the average temperatures fall below 12.8°C. An increase in PDD requires an increased heat supply to maintain an acceptable greenhouse temperature.). In addition, snowmelt was delayed by almost a month to late June and numerous mild frosts occurred throughout the season.

The most dramatic difference in the regional climatic picture was the significant reduction in bright sunlight hours recorded (Figure 8, Table 2). Skies were frequently overcast from June to August resulting in an average 37% reduction in Bright Sunlight Hours. In July only 197 hrs of bright sunshine were recorded, which was 48% of the recorded (1983-85) average (413 hrs) and only 27% of total daylight hours (720).

Given the below average weather conditions experienced in 1986, the performance of the greenhouse could be expected to improve in future years. An increase in radiant energy to normal levels would significantly increase heat availability to the greenhouse and likely improve plant performance and productivity.

3-2 GREENHOUSE MICROCLIMATE

The operation of the greenhouse may be divided into four distinct seasons or periods, each characterized by a general set of environmental conditions and requiring the implementation of different climate-controlling systems in order to maintain favorable conditions for vegetable production. The seasons are roughly delineated as follows:

[1] SUMMER : June - July
[2] FALL : August - September
[3] WINTER : October - March
[4] SPRING : April - May

The effective period of observation and production in 1986 extended from June to December to include 3 of the 4 seasons. Not all systems were immediately operational and conditions within the greenhouse fluctuated as problems were identified and solved. The solar collector and exhaust fan were not installed until August. A summary of the systems timetable for 1986 (with systems incomplete) is presented in Figure 9 and the expected operational timetable for future years (systems complete) is presented in Figure 10.

Temperatures and humidity levels inside the greenhouse were measured using Taylor maximum-minimum thermometers, rotating drum hygrothermograph, type J grounded thermocouple probes (iron/Constantan Duplex) and an Electro-therm HT 680 digital thermometer. Solar intensity was measured using a Quantum Instruments digital photometer.

3-2-1 SUMMER SEASON

Systems summary (1986) : (Figure 9)	[June to mid-August] Insulation OFF/ Canvas cover OFF Heater OFF/ Lighting Systems OFF Ventilation : Passive vents and fan to heat storage foundation (from inside greenhouse) (Fig 4)

In the summer months, the combination of warm ambient air temperatures (above 0°C) and extended solar hours was sufficient to maintain favorable growing conditions within the greenhouse. The daily maximum temperatures recorded inside the greenhouse for June, July and August averaged 24.5°C, 15.3°C and 14.8°C higher respectively than those recorded outside (Figure 11, Table 3). Similarly, average minimum temperatures were 13.8°C, 8.9°C and 9.0°C higher inside versus outside the greenhouse.

FIGURE 9 : Diagram of systems operational timetable for the 1986 season.

<table>
<tr><th></th><th colspan="3">SUMMER</th><th colspan="3">FALL</th><th colspan="2">WINTER</th></tr>
<tr><th></th><th>MAY</th><th>JUN</th><th>JUL</th><th>AUG</th><th>SEP</th><th>OCT</th><th>NOV</th><th>DEC</th></tr>
<tr><td>INSULATION
& COVER</td><td colspan="6">OFF</td><td colspan="2">▨</td></tr>
<tr><td>COLLECTOR
FAN</td><td colspan="3">GH peak into storage mass</td><td colspan="4">Collector functional</td><td>OFF</td></tr>
<tr><td>EXHAUST
FAN</td><td></td><td colspan="4">▨</td><td colspan="3">OFF</td></tr>
<tr><td>UNIT
HEATER</td><td>OFF</td><td colspan="3">6°C</td><td colspan="3">D = 20°C
N = 17°C</td><td>15°C</td></tr>
<tr><td>HALIDE
LAMP</td><td colspan="2">OFF</td><td colspan="4">1600 - 2300 hrs</td><td colspan="2">0-1oo - 2300 hrs</td></tr>
</table>

FIGURE 10 : Diagram of expected systems operational timetable in future years.

	SPRING April-May	SUMMER June-July	FALL **Aug-Sept**	WINTER **Oct-March**
INSULATION & COVER	OFF	OFF	OFF	▨
COLLECTOR FAN	▨	▨	▨	OFF
EXHAUST FAN	▨	▨	▨	**OFF**
UNIT HEATER	D = 23° C N = 17°C	6°C	D = 23°C N = 17°C	15°C
HALIDE LAMP	OFF	OFF	1600 - 2300 hrs	0700 - 2300 hrs

FIGURE 11 : Means of monthly minimum and maximum air temperatures (°C) recorded inside **versus** outside the greenhouse.

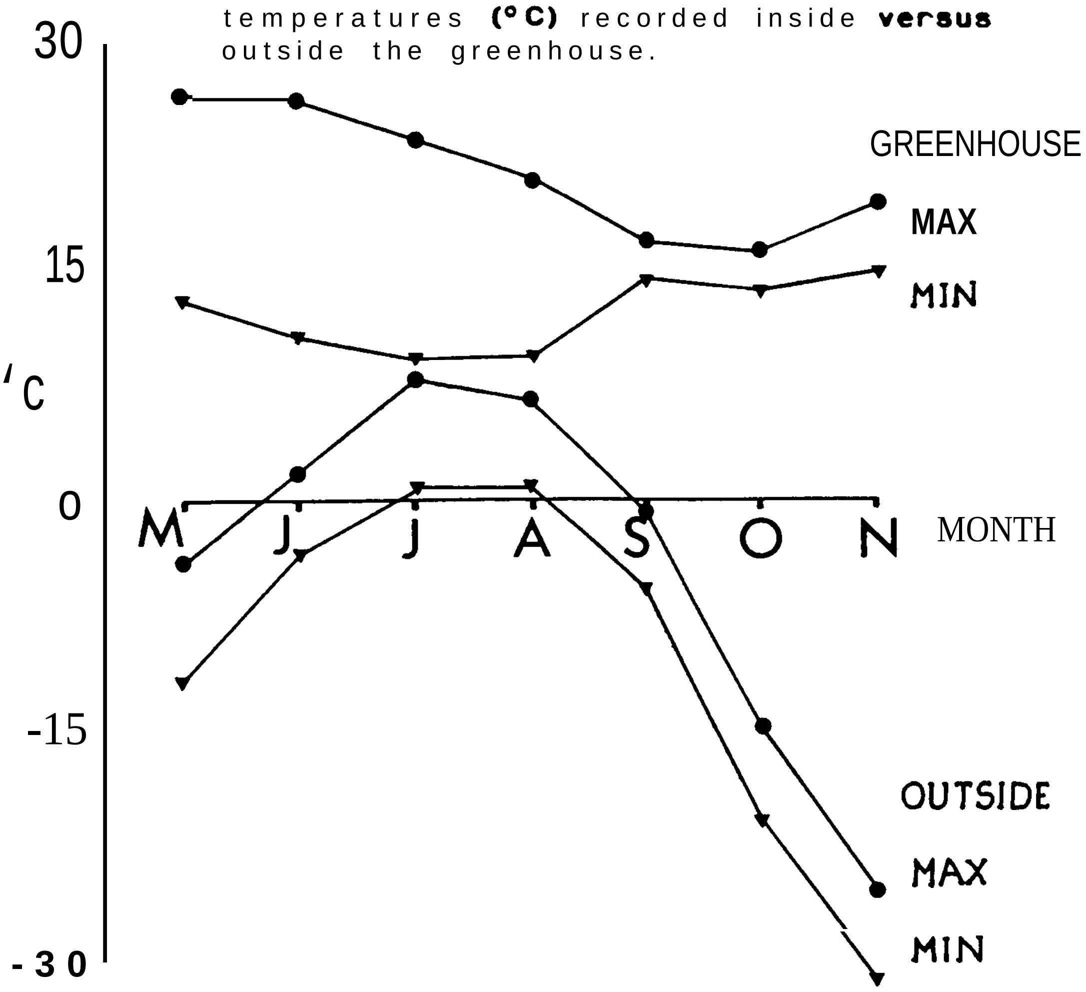


TABLE 3 : Means of monthly minimum and maximum air temperatures (°C) recorded inside versus outside the greenhouse.

Mean Maximum Temperature	MAY	JUN	JUL	AUG	SEP	OCT	NOV
AES	-4.7	2.1	7.7	6.5	-0.5	-15.0	-25.8
Greenhouse	26.8	26.6	23.0	21.3	17.1	16.7	19.2
Difference	31.5	24.5	15.3	14.8	17.6	31.7	45.0
Mean Minimum Temperature							
AES	-12.2	-3.4	0.4	0.6	-5.6	-20.9	-31.5
Greenhouse	12.9	10.4	9.3	9.6	14.5	13.5	15.0
Difference	25.1	**13.8**	8.9	9.0	**20.1**	34.4	46.5

The large differences between maximum and minimum temperature levels within the greenhouse also reflect the high degree of temperature fluctuation which occurred on a daily basis throughout the summer. An example of the daily course of temperatures is illustrated in Figure 12. On June 14, under sunny skies, temperatures within the greenhouse climbed rapidly to over 25°C by 700 hrs despite an outside temperature of -6°C. Temperatures were maintained between 23°C and 25°C for 12 hours through the operation of the heat storage fan mounted in the peak of the greenhouse (Figure 4). Without the benefit of the fan, temperatures could be expected to climb to over 40°C (Poole, 1985). After 1900 hrs, temperatures dropped gradually to evening levels (10-12OC). Under cloudy conditions, temperature fluctuations were much less pronounced and little or no fan operation was recorded.

For the months of June and July, temperatures within the greenhouse were controlled solely by passive ventilation through the gable end vents and operation of the temporary heat storage fan. When greenhouse temperatures rose to unfavorable levels (pre-set), excess heat from the peak was forced into the heat storage foundation, thus lowering temperatures. Cold air returning from the storage ducts further contributed to cooling the air. During periods of intense sunlight, the fan would operate almost continuously (30-45 min/hr) to maintain temperatures below 30°C.

As a result of the incomplete status of ventilating systems in 1986, the plants were subjected to short periods of unfavorably high temperatures in excess of 30°C. With the completion of the solar collector and installation of the exhaust fan, temperature regulation should greatly improve in the future. The collector/storage foundation fan can be expected to adequately circulate air and ventilate the greenhouse next summer. Excess heat building up at this time will be drawn out of the greenhouse by the exhaust fan. The effectiveness of the greenhouse in traPping solar energy in 1986 despite below-average conditions predicts more successful future seasons. (The possibility of producing crops in regions where cloud cover is generally heavier was also demonstrated) .

The relative humidity levels were particularly high in the early part of the summer as much of the ice trapped in the storage mass during construction of the foundation melted and entered the greenhouse in vapour form. Operation of the heat storage fan effectively reduced the humidity levels but it was not until the exhaust fan was installed in August that this excess moisture could be virtually eliminated from the greenhouse. During extended cloudy periods before this time, the condensation of moisture would completely coat the glazing and contribute to reducing light levels.

The amount and intensity of direct solar radiation reaching the greenhouse plants varied considerably according to the hour and day - depending on solar position and degree of cloud cover. Light intensity values were recorded as of August 1 when the photometer was received. Intensities at this time ranged from 1000 to 3000 footcandles under sunny skies and between 500 and 800 footcandles under overcast skies. Portions of the greenhouse were shaded at different times of the day by the adjacent hotel wings (see shadows cast Photos 4 and 5). The three soil beds bordering the southern wall of the greenhouse received an average of 3 hrs less direct sunlight per day than did the beds on the north side. This effect was least pronounced in June when the solar angle was at its maximum level of 43° and became increasingly noticeable towards the end of the season. By mid-August, the southern half of the greenhouse growing beds received no direct sunlight between 1000 and 1600 hrs.

3-2-2 FALL SEASON

Systems summary (1986) : (Figure 9)	[Mid-August to Hid-October] Insulation OFF/ Canvas Cover OFF Heater ON : August (6°C) Sept-Oct (20°C Day/ 17°C Night) Lighting Systems ON (1600-2300 hrs) Ventilation : Passive vents (Aug) Solar collector fan to heat storage foundation (Sept. only).

In late August and September a decrease in ambient air temperatures outdoors combined with a reduction in both daylength and total Bright Sunshine Hours required the use of supplementary heating and lighting in the greenhouse. In late August the heater was set at 6*C and switched itself on intermittently when outdoor temperatures dropped below zero in the evenings. Figure 13 illustrates a typical diurnal curve for August. During the daytime, solar radiation would adequately heat the greenhouse to 15 - 20°C (clear day). Temperatures would gradually decrease throughout the evening until the heater was activated at 6°C.

In September the heater, set at 20°C, was utilized 24 hrs per day to maintain growth temperatures. Average daily maximum and minimum temperatures for September were 17.6°C and 20.1°C higher inside the greenhouse than outside. At the end of the month, temperature differences of up to 37°C were recorded between greenhouse and outside air temperatures. As temperatures continued to drop in late September, the heating demand increased and the heater oPerated nearly continuously. Ventilation was greatly reduced during this period as vents were kept closed and exhaust fan was off.

FIGURE 12 : Diurnal course of air temperatures recorded inside versus outside the greenhouse on June 14, 1986.

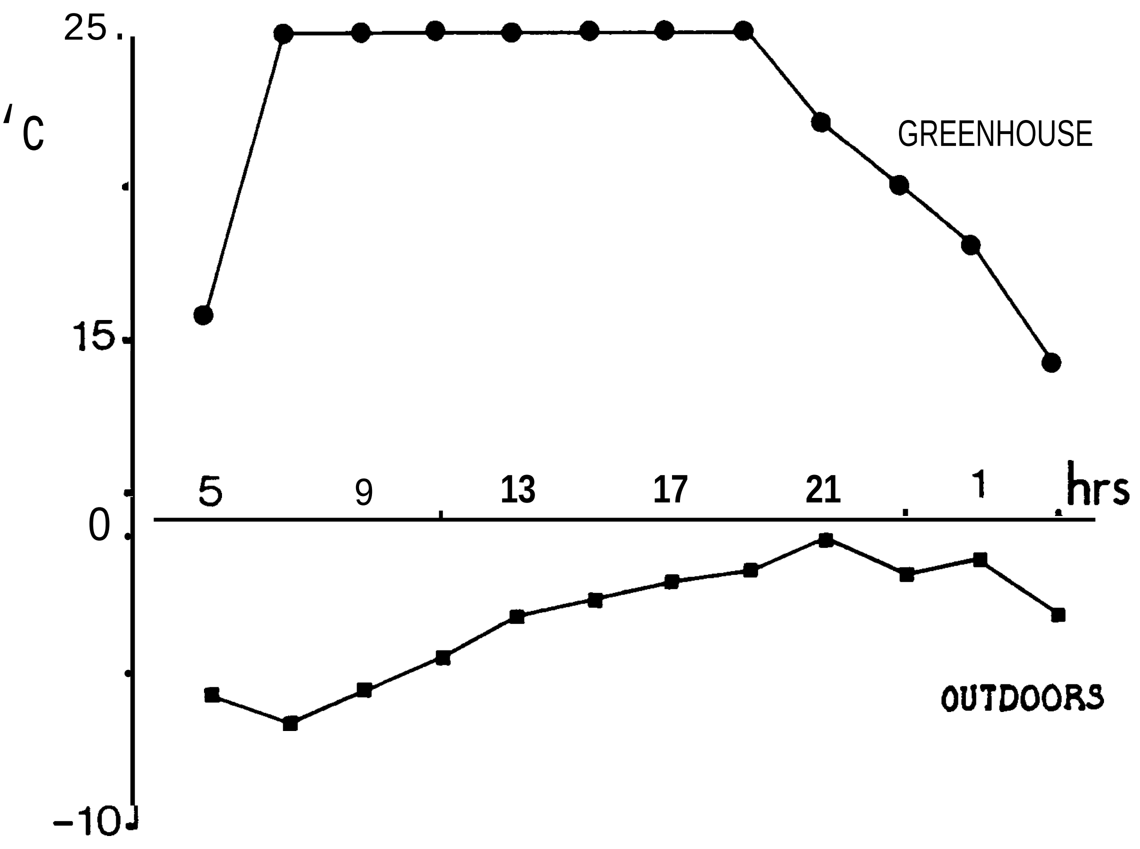
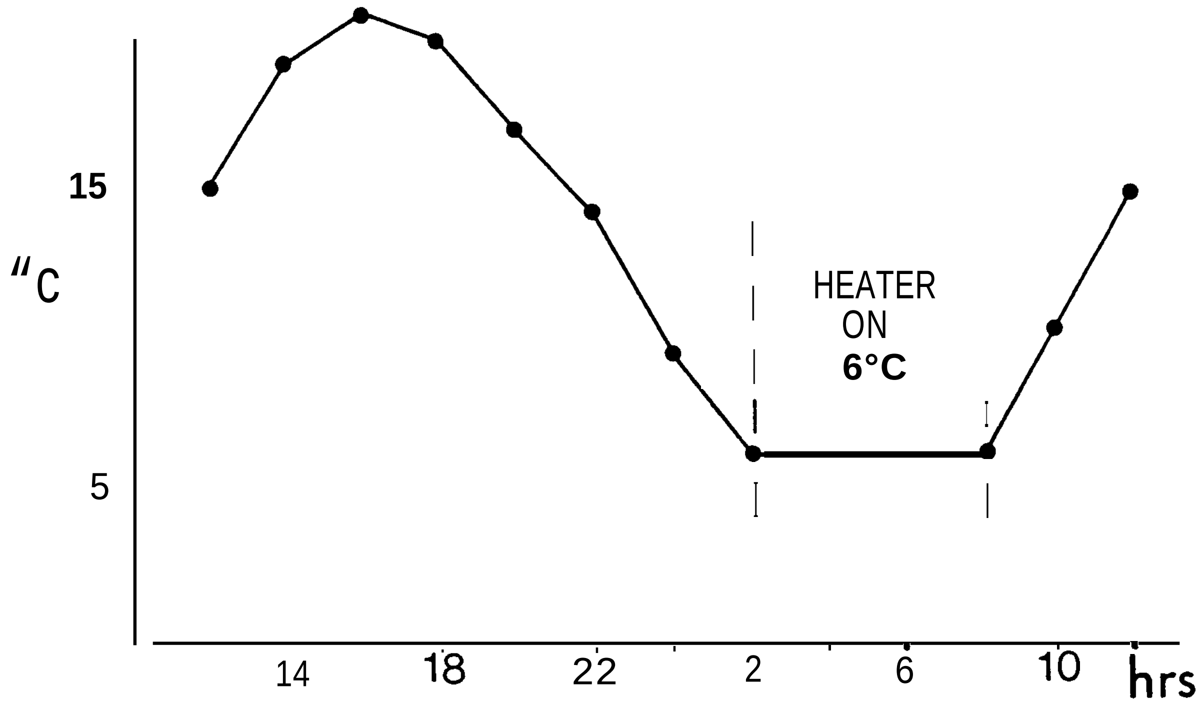


FIGURE 13 : Diurnal course of air temperatures recorded at plant level inside the greenhouse on August 18, 1986.



During September, a Pronounced stratification in greenhouse temperatures was observed. Temperature differences of up to 15°C were observed across a vertical profile (Figure 14). Temperatures were coldest within the heat storage mass and became progressively warmer towards the ceiling. The fixed setting of the heater thermostat resulted in very steady temperatures throughout the day. In the evenings, a small fluctuation in temperatures was effected by turning the thermostat 5°C down.

The solar collector, which was completed at the end of August, operated on clear sunny days in September. Air was heated to 45*C in the collector panels and delivered to the heat storage foundation. The contribution of this heat to greenhouse microclimate cannot be assessed at present as temperature sensing probes (thermocouples) were not installed until the end of the month. Cold air returning from the storage ducts did, however, cause a drop in greenhouse temperatures which triggered the glycol heater unit.

A further reduction in the solar angle of incidence in September (14°) increased the degree of greenhouse shading from the hotel and effectively eliminated any direct sun striking the soil beds between 1000 and 1800 hrs daily. This factor, combined with a shorter day length period and reduced number of Bright Sunshine Hours, necessitated the use of supplementary lighting in the fall season. The metal halide lamp automatically switched on from 1600 to 23oo hrs daily. During the day, light intensities at the level of the soil beds ranged from 700 to 900 footcandles under clear sunny skies to a low of 200 footcandles under cloudy skies (with lamp off). Intensities were greater (1200-1500 ftc) at the level of the hanging planters where tomato and cucumber plants still received direct sunlight.
Humidity levels remained stable within the greenhouse at between 65% in the day and 85% in the cooler evenings.

The climate around Pond Inlet and overall operation of greenhouse systems can be expected to be similar in future fall seasons. The addition of a circulating fan (Dee 1986) should reduce temperature stratification and improve air circulation within the greenhouse. Lighting systems will be required to operate longer at this time of year in order to adequately satisfy growth requirements. The transition date between fall and winter seasons has been set at the end of September for the Pond Inlet greenhouse. At lower latitudes however, this date may be extended by almost a month.

FIGURE 14 : Diurnal course of greenhouse temperatures (air, NFT bed, heat storage foundation) recorded on October 1, 1986.

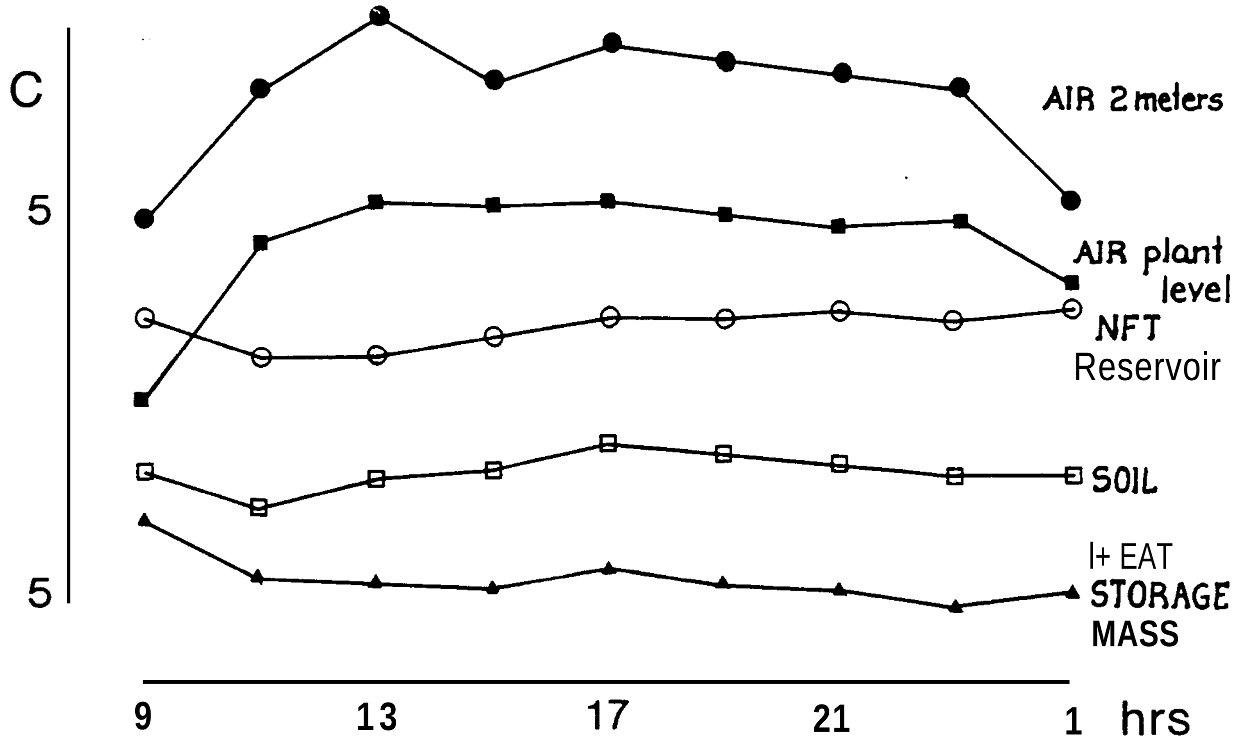
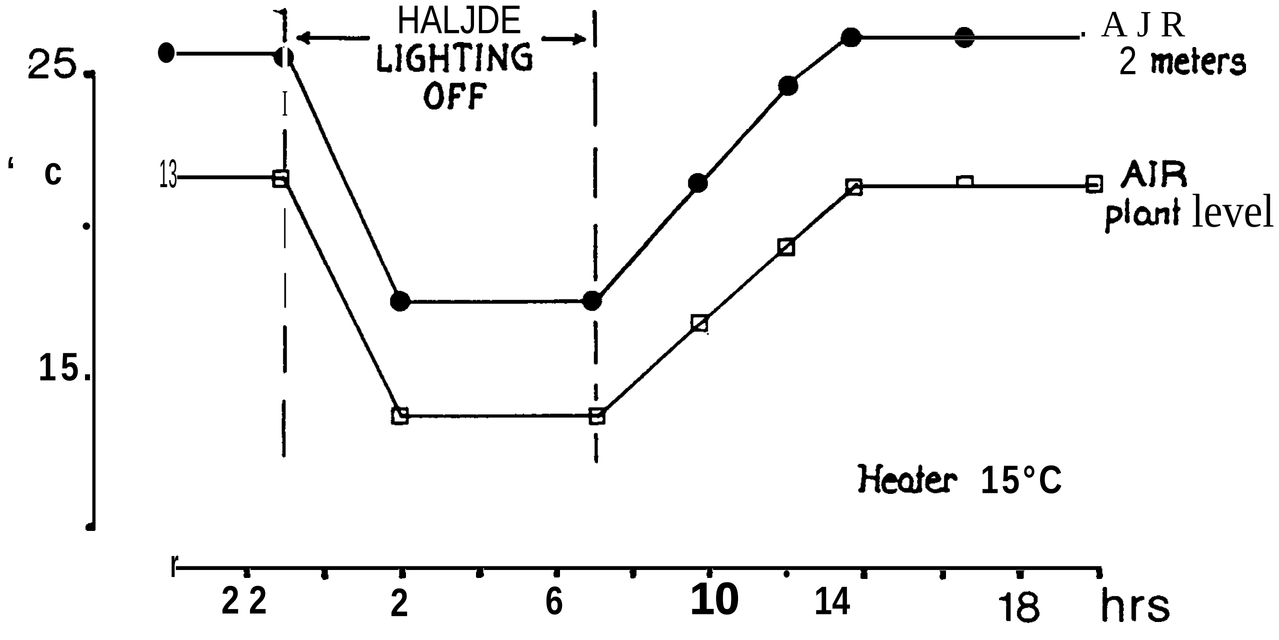


FIGURE 15 : Diurnal course of greenhouse air temperatures recorded at plant level on November 30, 1986.



3-2-3 WINTER SEASON

Systems summary (1986) : (Figure 9)

[Mid-October to December]
Insulation ON/ Canvas Cover ON
Airlock ON / Heater ON (15°C)
Lighting Systems ON
Ventilation : Circulating fan
(December only).

Winter extends from October to April and represents the longest growing period having one set of conditions. Extremely low temperatures and complete darkness require the continuous use of artificial heating and lighting systems to maintain favorable growth conditions.

In October and November, mean temperatures outside the greenhouse averaged -12°C and -28.7°C respectively. Inside the greenhouse, maximum daily temperatures measured at the level of the soil beds averaged 16.7 and 19.2°C while minimum temperatures averaged 13.5 and 15°C for October and November respectively (Figure 11, Table 3).

In 1986, daytime temperatures inside the winterized greenhouse were maintained solely by heat emitted from the halide and neon lamps and their ballasts. Figure 15 illustrates a typical diurnal course for the greenhouse. Temperatures attained a maximum and remained at a constant level from 1400 to 2300 hrs. After the lamp was extinguished at 2300 hrs, temperatures dropped to 14°C (at plant level) where they were maintained by the heater until 0700 hrs when lights came back on. The unit heater operated an average of only 1 hr in each 24 hr period, reflecting the low degree of heat loss from the structure.

As in the fall season, temperatures in the winterized greenhouse were considerably stratified with a range of 35°C recorded between the sand in the heat storage foundation and air temperature at the greenhouse peak (2 meters above plants) (Figure 16). The sub-zero temperatures recorded in the heat storage foundation suggest that the uncovered storage mass acts as a heat sink in winter, drawing heat from the greenhouse air into the soil.

Humidity levels were also elevated in winter, averaging 70X RH in the day and rising to 85-90X RH at night.

FIGURE 16: Diurnal course of greenhouse temperatures (air, NFT bed, heat storage foundation) recorded on November 26 and 27, 1986.

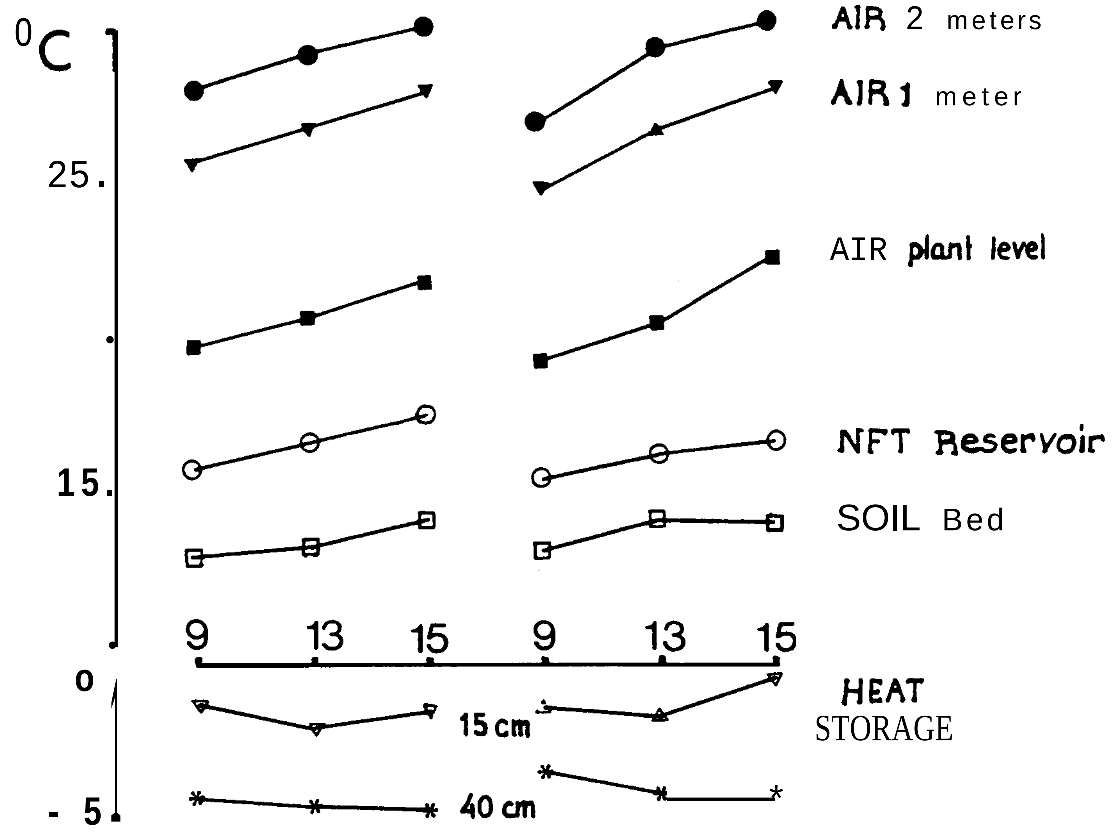
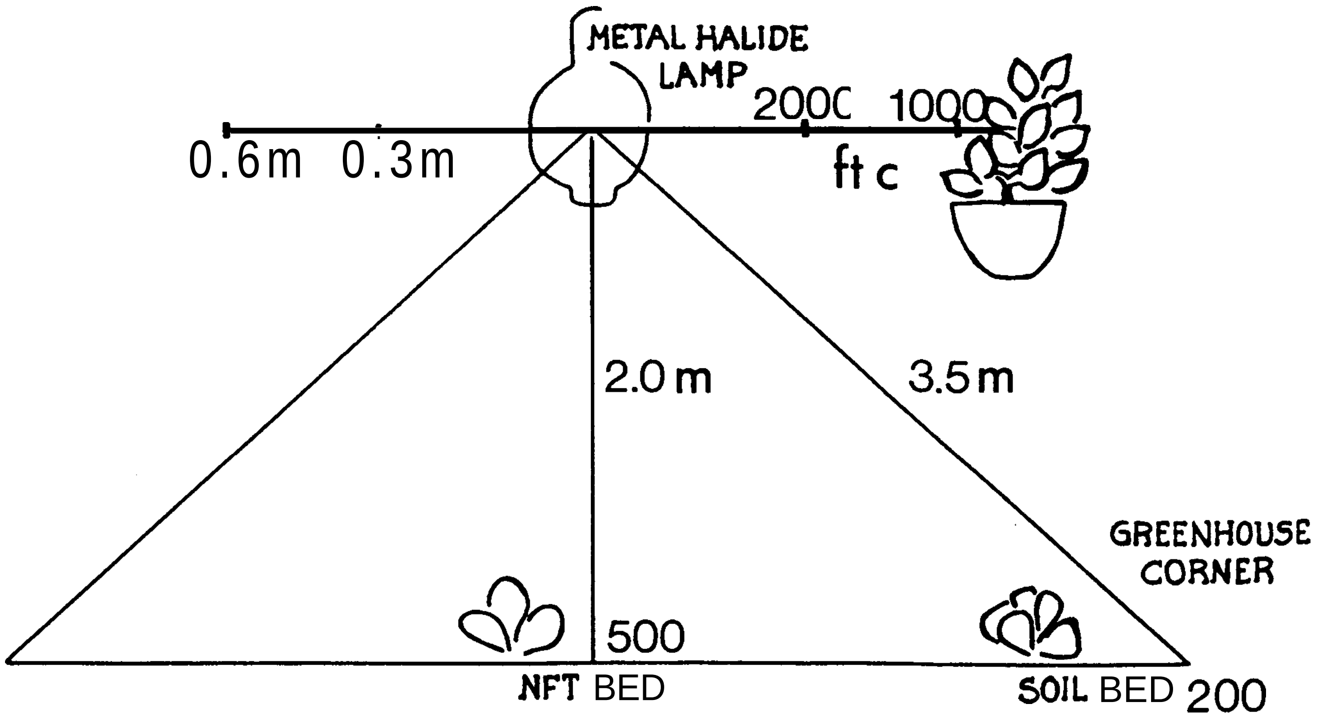


FIGURE 17: Light intensities (footcandles) at various locations inside the winterized greenhouse.



Observed reduction in heating requirements, widely stratified temperatures and increased humidity levels may all be attributed to a reduction in ventilation and air circulation in the winterized greenhouse. Ventilation occurred at very low rates mainly through cold air seepage from the cracks in the insulation and doorway and a small drainage vent in the foundation. The inadequacy of existing systems may have resulted in reduced production, decreased transpiration rates and C02 availability to plants. The addition of a circulating fan in late December is expected to improve air circulation within the greenhouse but a more efficient system of ventilation and air exchange should be developed to improve growing conditions in future seasons.

Light levels and photoperiod remained constant throughout the winter as they were fully controlled by timer and fixed intensity light sources. The intensities emitted by the metal halide lamp are illustrated graphically in Figure 17. The intensity of light varied according to the location of the plants within the greenhouse and their distance from the lamp. The hanging planters (0.6 - 1.2m distance) received the strongest illumination of 1000 to 2000 footcandles. The NFT bed (1.8m) averaged 600 ftcandles while the corners of the greenhouse (3.0-3.5m) and most soil beds averaged only 200-300 ftcandles. The foil backing of the insulation may have increased light levels by reflecting light down to the beds and around the back sides of planters.

3-2-4 SPRING SEASON

Spring : Expected Systems Operation (Figure 10)
[April and May)
Insulation OFF/ Cover OFF
Solar Collector fan ON
Heater ON (23°C/17°C).

In the spring, ambient temperatures outside the greenhouse remain cold but levels of solar radiation are sufficiently high to permit warming of the greenhouse and illumination of plants. As in September, supplementary heat will be required to maintain favourable conditions throughout the nights and on overcast or unseasonably cold days. It is expected that due to low outdoor temperatures, the heating load may be as high in the spring as it was in the fall. The reflection of sunlight from snow and a high number of bright sunlight hours will make a greater contribution to heating the greenhouse than in the fall, although partial Shading of the soil beds will continue until the solar angle increases. The problems of temperature stratification and insufficient air circulation will be diminished by oPeration of the solar collector but inadequate air exchange and high humidity will continue to be problems.

Section 3-3 GREENHOUSE ENERGY BALANCE

Heat loss out of and heat gain by the greenhouse were assessed using climatic data collected by the Atmospheric Environment Service of Environment Canada.

3-3-1 CALCULATION OF HEAT LOSS

The estimation of heat loss is directly related to the area of the building exposed to the exterior, the difference between inside and outside temperatures and the insulating value of construction materials.

$$\text{HEAT LOSS} = \frac{\text{Surface Area (m2) x Temperature Difference } (\Delta T^{\circ}C)}{(RSI)\text{ Total Insulating Value}}$$

(Craft, 1983)

The determination of greenhouse heat loss is presented in Table 4 and thermal resistance values(RSI) for the different Construction materials are found in Table 5.

The total heat loss estimated to occur in the uninsulated greenhouse (spring to fall seasons) is 714 KJ/°C/hr (Table 4). This value is reduced by 66% to 244.5 KJ/°C/hr upon installation of insulating panels. The greatest proportion of heat loss occurs through the glazing. Glazing heat loss in the uninsulated greenhouse is estimated to be 497 KJ/°C/hr or 70X of total heat loss. During the winter months, glazing heat loss is reduced to only 27 KJ/°C/hr or 11% of total heat loss (244.5 KJ/°C/hr) when insulating panels are installed.

During the winter season, almost half the the total heat loss from the greenhouse occurs through the exchange of air during ventilation (113 KJ/°C/hr assuming 2 complete air changes per hour) . During 1986, this value was probably much lower as a result of reduced air exchange and ventilation inside the greenhouse. This considerable heat loss resulting from air exchange in winter could be reduced by using air to air heat exchangers or attaching arctic greenhouses to existing buildings.

Peak greenhouse heat loss estimated for a design temperature of -54°C was 38.571 KJ/hr without and 13.202 KJ/hr with insulative panels.

3-3-2 ANNUAL ENERGY BALANCE : METHODS

The Net Energy Balance for the greenhouse has been calculated for a full operational year and is presented in Table 6. This table used averaged data and estimates based on the operational summary presented in Figure 10. The table is comprised of 4 sections :

[A] AVERAGE MONTHLY HEAT LOSS (KJ/month)

Mean monthly heat loss is obtained by multiplying total greenhouse heat loss (Table 4) by the number of Plant Degree Days/ month (Table 1).

AVERAGE MONTHLY HEAT LOSS (KJ) = Total Daily Heat Loss (KJ/deg.day) x Plant Degree Days/month

[B] MONTHLY SOLAR HEAT CONTRIBUTION (KJ/month)

Calculated for the period between April and September using Daily Solar Energy values (KJ/m2 at 60° glazing surface) for Resolute Bay (AES) and the average hours of Bright Sunshine for Pond Inlet (Table 2).

Hourly average Solar Energy (KJ/m2) = Daily Total Solar Energy (KJ/m2) (AES Resolute Bay) -:- Hours Daylight (Fig 8)

SOLAR HEAT COLLECTABLE / MONTH (KJ) = Total Glazing Area (Table 4) x Light Transmission Factor (0.83) x Bright Sunshine hrs/month (Table 2) x Hourly Average Solar Energy

The solar heat contribution was estimated for the combined areas of the south-facing glazing and the solar collector panel .

[c] MONTHLY EQUIPMENT HEAT CONTRIBUTION **(KJ/month)**

All electrical equipment generated heat in direct proportion to its rated wattage. This contribution has been calculated by multiplying **KWatt** hours of operation for each piece of equipment by 3,600 KJ/hr (Power engineering standard).

HEAT GAIN (KJ/month) = **KWatt hrs/** month x 3,600 KJ/ **hr**

The equipment is rated as follows:

1. Metal halide lamp and ballast	1.55 **kW/hr**
2. Neon lamps and ballasts	0.70 **kW/hr**
3. Collector fan	0.30 **kW/hr**
4. Exhaust fan	0.14 **kW/hr**
5. Heater fan	0.20 **kW/hr**
6. Hydroponic pumps	0.12 **kW/hr**

The estimated hours of equipment operation are presented in Section 5-1 (Production Costs).

[D] NET GLYCOL HEATER CONTRIBUTION **(KJ/month)**

This has been estimated as the difference between the calculated heat gain and heat loss.

$$\text{HEATER CONTRIBUTION [D] (KJ/month)} = \text{AVERAGE HEAT LOSS [A]} - \left[\text{SOLAR HEAT GAIN [B]} + \text{[C] EQUIPMENT HEAT GAIN}\right]$$

The heat contribution of the **glycol** may be translated into expected hours of heater operation per month. The determination of this value is made in Section 5-~.

Table 4 : Calculation of greenhouse heat loss.

DESIGN TEMPERATURE (1) = Coldest Outdoor Temperature -47° c - Minimum Indoor Temperature 7° C = 54° c

GREENHOUSE **FRAME** HEAT LOSS

ROOF : $\frac{\text{Area}}{\text{RSI}} = \frac{9.66 \text{ m2}}{1.57} = 6.15$ W/m2 (2)

DOOR : $\frac{1.67}{0.32} = 5.22$ W/m2 (3)

VENT : $\frac{0.09}{0.11} + \frac{0.03}{0.31} = 0.91$ W/m2 (4)

INSULATED FOUNDATION = 19.52 m (Perimeter) x 0.86 W/m2 = 16.79 W/m2 (5)

AIR CHANGE = 47.39m2 (Volume) x 2 changes hour x 0.33 = 31.28 W/m2 (6)

TOTAL HEAT LOSS GREENHOUSE FRAME = (2 + 3 + 4 + 5 + 6) = 60.35 W/m2 (7)

GLAZING HEAT LOSS

TOTAL AREA = 14.88 m2 South + 13.37m2 North + 8.14 m2 West + 6.41 m2 East = 42.8 m2

WITHOUT INSULATION = $\frac{\text{Area m2}}{\text{RSI}} = \frac{42.8 \text{ m2}}{0.31} = 138.06$ W/m2 (8)

WITH INSULATION = $\frac{\text{Aream2}}{\text{RSI}} = \frac{42.8 \text{ m2}}{5.66} = 7.56$ W/m2 (9)

TOTAL GREENHOUSE HEAT LOSS

WITHOUT INSULATION = 60.35 W/m2 (7) + 138.06 W/m2 (8) X 3.6 KJ/W-hr = 714.28 KJ/°C/hr (lo)

WITH INSULATION = 60.35 W/m2 (7) + 7.56 W/m2 (9) x 3.6 KJ/W-hr = 244.48 KJ/°C/hr (11)

PEAK GREENHOUSE HEAT LOSS

WITHOUT INSULATION = 714.28 KJ/°C/hr (lo) x 54 °C (1) = 38,571 KJ/hr

WITH INSULATION = 244.48 KJ/°C/hr (11) x 54 °C (1) = 13,202 KJ/hr

TABLE 5 : Thermal resistance values **(RSI)** for greenhouse materials and structures.

GLAZING :

Acrylite SDP (double glazed)	0.31	

GLAZING WITH INSULATION :

Indoor Air Film	0.12	
Thermax Insulation (100 mm)	4.93	
Air Space (50 mm)	0.17	
Acrylite SDP (double glazed)	0.31	
Canvas Cover	0.10	
Outdoor Air Film	0.03	5.66

FOUNDATION WALLS :

Plywood Sheathing (19 mm)	0.13	
Air Space (65 mm)	0.17	
Extruded Polystyrene (114 cm)	3.66	
Air Space (65 mm)	0.17	
Plywood Sheathing (19 mm)	0.13	
Outdoor Air Film	0.03	4.29

GREENHOUSE ROOF :

Indoor Air Film	0.12	
Plywood Sheathing (11 mm)	0.10	
Extruded Polystyrene (38 mm)	1.22	
Plywood Sheathing (11 mm)	0.10	
Outdoor Air Film	0.03	1.57

SOLAR COLLECTOR (FRONT) :

Outdoor Air Film	0.03	
Acrylite SDP Glazing	0.31	
Air Space (25 mm)	0.17	
Sheet **Metal**	Oft	0.62

SOLAR COLLECTOR (BACKING) :

Thermax Insulation (25 mm)	1.23	
Plywood Sheathing (11 mm)	0.10	
Indoor Air Film	0.12	1.45

TABLE 6 : Summary of greenhouse annual energy balance

	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
(A)												
TOTAL DAILY HEAT LOSS : (A) **with insulation** **(B) without** insulation **(KJ/Degree Day)**	6,667. 5	5,667.6	6.267.8	17,1 42.7	17,142.7	17,142.7	17.142.7	I7,142.7	1?, 142.7	8,467.5	5,667.5	8,667.6
PLANT DEGREE DAYS	1* 296.9	1,313.1	1,31r.4	1 ,037.6	691.2	369.1	261 .0	276.2	453.0	615.3	1,066.1	1, 2s6 .4
TOTAL MONTHLY HEAT LOSS (K..)) **(KJ/hour)**	7,621,296 10,244	7,704,614 11,465	7,729,646 10,390	17,787,266 24,70S	49.s49,034 15,926	6,327,371 8,788	4,302,010 5,783	4,734,ss4 6,364	7,76S,643 10,7s6	4,783,?73 6,430	6,312,692 8,851	7,s47,962 10,145
(B)												
DAILY TOTAL SOLAR ENERGY (KJ/m2)	o	2,600	15,600	26,s00	28,000	24,200	17,600	13,200	8,500	4,200	10	0
HOURLY AVERAGE SOLAR ENERGY (KJ/m2/hr)	o	555.6	1,39S.2	1.632.9	1,201.7	1,008.3	741.7	660.4	643.9	536.6	10	0
HOURS BRIGHT SUNSHINE (Table 2)	o	49.8	151.1	308.1	400.6	336.9	413.0	224.4	SS.6	21.0	0	0
TOTAL SOLAR HEAT COLLECTABLE (KJ)												
(1) Greenhouse	o	341,ss4	2,609,231	5,832,896	5,945,430	4,220,346	3,703,133	1,885,574	704,536	139,679	0	0
(2) Solar collector	o	170,843	1,304,616	2,916,446	2,972.71S	2,110,173	1,891,566	942,787	3S2.2S6	69,039	0	0
TOTAL (KJ) (1 + **2)** **(KJ/hour)**	o o	512,529 763	3,9*3,647 5,261	0.749,343 12,152	0,910,14s 11,987	6,330,619 8,792	8.674,696 7,627	2,828,361 3,801	1,056 804 1,468	209,619 282	0 0	o 0
[C]												
Metal Halide Lamp	2,779.2S0	2,S03,0S0	2,771,280					1,212,480	4,173,240	2,771,280	2,682,000	2.171,2S0
Fluorescent Lamps	1,257,120	1,135,440	1,257,120					1,257,120	1,216,440	1,267,120	1,216,440	1,257,120
1. @nectar **Fan**			81,648	166,320	216,360	183,240	223,200	121,320	47,s60			
2. Exhaust Fan				38,160	49.ss0	42,120	51,480	27,720	11,160			
3. **Heater Fan**	342,720	39s,2s0	34s,s00	890,280	2s6,s60				481,320	54,360	227,160	335,160
Hydroponic Pumps	308,160	278,280	308,160	298,080	308,160	29s,0s0	308,160	30s,160	298,080	308,160	29s,060	308,160
EQUIPMENT HEAT CONTRIBUTION (KJ) **(KJ/hour)**	4,679,2S0 6,2S9	4,311,360 6,416	4,763,S03 6,403	4,392,S40 1,936	860,760 1,157	523,440 727	582,840 783	2,926,800 3,934	3,226,200 4,464	4,390,920 6,902	4,423,680 6,144	4,671,720 6,279
(D)												
NET GLYCOL HEATER CONTRIBUTION (KJ) **(KJ/hour)**	2,943,394 3,986	3,394,7% 5,062	2,966,92s 3,9s9	7,64s,028 10,619	2,072,306 2,7S8	o o	0 0	0 0	3,480,746 4,034	393,113 528	1,960,926 2,710	2,878,466 3,ss9
Heater Hours	% . 2	109.8	96.0	247.3	79.6	0	0	0	133.7	15.1	63.1	93.1
PERCENT CONTRIBUTION 70 **TOTAL HEATING REQUIREMENT** :												
[B]	00.0	00.0	00.0	49.2	7s.3	100.0	two	89.7	13.6	00.0	00.0	00.0
[C]	61.4	56.0	61.6	18.3	7.3	00.0	00.0	40.3	41.6	91.8	69.4	61.9
[D]	36.6	44.0	3s.4	32.s	17.4	00.0	00.0	00.0	44.6	e.2	30.6	38.1

3-3-3 ANNUAL ENERGY BALANCE : EVALUATION

When considering the data presented in Table 6, it is essential to take the following factors into account :

1. Air exchange rates (Table 4), calculated at 2 complete changes per hour may vary considerably particularly in **summer** when ventilation is increased (Increased air exchange = increased greenhouse heat loss).
2. Daily Total Solar Energy values [B] obtained for the Resolute Bay weather station (no data available for Pond Inlet) may actually be higher for Pond Inlet where less cloud cover is experienced in an average year.
3. Solar heat absorption values were based on 60° glazing angle [B] for all sides of the greenhouse when the east and west gable end **walls** are actually at 90°. The estimated values do not take into consideration shading of the greenhouse by the hotel for parts of each day. Solar heat contribution was based solely on Bright Sunshine hours without considering heat gained on lightly overcast days. The effect of wind activity on heat loss was not estimated.
4. Calculation of heat production by the **glycol** heater is only an estimated value based on flow rates of the heating medium and the temperature differential between incoming and outgoing lines.

[A] HEAT LOSS

The degree of heat loss from the greenhouse varied from month to month as a direct result of mean outdoor temperatures and the degree of insulation provided. As expected, heat loss is **lowest** during the **summer** months, averaging between 6,364 and 8,788 **KJ/hr.** Values are highest in the spring (15,926 - 24,705 **KJ/hr)** when cold outdoor conditions are combined with the removal of the protective insulation. **Despite** very cold temperatures, heat loss in the winter averages between 6,430 and 11,465 **KJ/hr** and is lower than values estimated for both spring and fall. These **low** values demonstrate the contribution of the insulating panels to reducing heat loss in the winterized greenhouse.

[B] SOLAR HEAT CONTRIBUTION

The contribution of heat energy to the greenhouse is directly correlated to the amount of Bright Sunshine hours received by the glazing (Figure 8, Table 6). Although some degree of radiation is recorded between February and October, the most significant contribution occurs fom April to July. At this time, the long daylight hours and low cloud cover result in large heat gains by the greenhouse. The potential contributions are highest in April and May, at estimates of 12,152 KJ/hr and 11,987 KJ/hr (estimated over 24 hrs) respectively. Values decrease progressively throughout the year until September when an average contribution of only 1,468 KJ/hr can be expected. Some radiation is also present in March and may be captured by the solar collector, but the extremely cold temperatures in this month do not favour removal of the protective insulation.

[C] EQUIPMENT HEAT CONTRIBUTION

The operation of fans and lights represents a substantial heat energy source in a small greenhouse particularly in the winter season when lighting systems are operating at a maximum. Equipment heat contributions during the winter are more or less constant from month to month ranging from 5.902 KJ/hr to 6.416 KJ/hr. The combination of neon and halide lamps account for 85% of this total while the heater fans and pumps account for the remaining 15%. The heat addition from the circulating fan installed in December has not been calculated, however its low wattage (less than 0.1 Kw/hr) would make its heat contribution to the greenhouse negligible (<5%). The total equipment heat contribution is reduced by 75% in April (1,935 KJ/hr) when lighting systems are shut down for the spring and summer. In August and September, the use of supplementary lighting once again contributes somewhat to heat gain.

[D] GLYCOL HEATER CONTRIBUTION

Based on the values calculated in Table 6, heater operation (and energy contribution) is expected to be greatest in April and September, when cold outdoor air temperatures combine with high heat loss from an uninsulated greenhouse to create a significant heat demand (24,705 KJ/hr). In April, a large portion of this demand is provided by the sun (12,152 KJ/hr) and the remainder by the heater (10,619 KJ/hr). It is uncertain at this point whether the heater will be capable of maintaining suitable temperatures within the greenhouse during April.

In the winter, the heater may be expected to produce between 528 KJ/hr in October and 5,051 KJ/hr in February, the coldest month. In November 1986, a total of only 20.8 hours of heater operation were recorded (33% of expected value), demonstrating once again a reduction in heat loss presumably caused by inadequate ventilation in the greenhouse.

[E] PERCENT CONTRIBUTION

The relative importance of each of the three principal heat sources (solar radiation, equipment and heater) may be determined by examining their percent contribution (monthly and annual) to the total heating requirement. In this way, it is possible to obtain a clearer picture of the importance of systems in the annual energy balance.

Over the winter months, heat generated by equipment (primarily lights) represents an averagae of 67% of requirements. The remaining 33% is provided by the heater. In October, the warmest winter month, equipment alone supplies 92% of the required heating load. In future designs, the contribution of the heater in the winter will be directly determined by the effectiveness of the insulating systems at reducing heat loss.

In the spring and summer, solar radiation is expected to provide between 50X and 100% of the heating load with the heater as the principle backup (32-38X). A net heat gain occurs only in June and July when heat loss is at its lowest levels.

In September, solar contribution decreases considerably (14%) and the heating load is carried equally by the heater (45%) and equipment(42%).

This data suggests therefore, that the role of the heater and requirements for active heat input may be lower than originally anticipated. In winter this is largely a result of the major contribution of the insulation towards reducing heat loss from the greenhouse. A reduction in estimated solar heat input resulting from local factors such as unusually cloudy conditions in a given year or partial greenhouse shading may increase the required heat load of the heater unit. It is therefore essential that future designs attempt to optimize (1) solar capture by the greenhouse and (2) insulation systems to Prevent heat loss.

3-4 AN EVALUATION OF SYSTEMS FUNCTION

In this section, each component of the greenhouse control systems and structure will be assessed for positive and negative features in design and operation. Modifications suggested may benefit future small-scale greenhouses built in arctic regions. Assessment is based on the operating period from June to December with speculation on effects in the spring season. Additional recommendations and a modified design are presented in Section 7-4.

3-4-1 LOCATION OF GREENHOUSE

The sheltered location between two wings of the Sauniq Hotel contributed to reducing wind activity and improving heat retention of the greenhouse in 1986. The proximity of an independent structure provided the greenhouse with a source of power, heat and water and eliminated the need for costly independent systems. This arrangement may prove to be more cost effective for small community installations than expensive capital cost expenditures.

In addition, the possibility exists for the construction of venting which would permit an exchange of air between the greenhouse and hotel . Such a system could supply the hotel with some heat in the spring and summer while ensuring adequate air exchange for the greenhouse throughout the year. The lack of such a system in Pond Inlet resulted in reduced air circulation and gas exchange in the winterized greenhouse. Alternately, a direct walk-in corridor linking the hotel to the greenhouse would provide the necessary improvement in ventilation and further decrease heat loss by acting as an efficient air lock.

The distance separating the hotel from the greenhouse was very small (2-3m) and resulted in the shading of plants in the growing beds for varying periods during the season. The resulting reduction in light intensities probably contributed to decreased plant productivity as well as reduced heat input to the greenhouse. Future site planning must ensure unobstructed access to sunlight, especially from the east, south and west hemispheres.

3-4-2 HEAT STORAGE FOUNDATION

In summer, the delivery of heated air from the peak of the greenhouse into the storage foundation effectively improved microclimatic conditions in a number of ways:

[1] As a cooling system - Temperatures in the greenhouse were reduced by (a) delivery of heated air into the foundation and (b) return of cool air from the storage vents. Temperature fluctuations in the greenhouse were also reduced resulting in a more stable growing environment.

[2] As a ventilating system - The operation of the fan improved air circulation and reduced stratification of indoor temperatures. The pressure drop during fan operation also drew in outside air through exterior vents and contributed to ensuring adequate gas exchange for plants.

[3] As a heat storage mass - The excess heat stored during the day in the sand may have contributed to the warming of the greenhouse at night. This contribution could not be properly assessed due to lack of necessary instruments. The storage of excess heat during periods of increased availability is an important priority for northern greenhouses.

[4) As a dehumidifier - The sand foundation was particularly effective in dehumidifying the greenhouse air in spring and summer. The use of a closed system of this type reduces the need for exterior ventilation to control humidity and therefore decreases heat loss from the greenhouse.

The use of sand as a storage medium is useful under northern conditions where the availability of coarse aggregate presents a problem and sub-zero temperatures make the use of water impractical. The heat storage capacity of sand is, however, only an estimated 30% that of water and therefore much larger volumes and more elaborate delivery systems are required to achieve the same effect.

The design of the Brace Institute's heat storage foundation allows for the installation of an insulated floor above the storage mass. In Pond Inlet, the lack of an insulated floor presented several disadvantages :

1. Heat transfered from the storage mass to the greenhouse could not *be* regulated and the effective storage time was **likely** reduced.
2. **In** the winter, the storage mass temperatures dropped below zero and heat was lost from the greenhouse into the foundation.
3. Operation of the storage fan in the early spring and late fall resulted in the release of cold air from the foundation and a cooling of greenhouse temperatures.

Based on these observations, it is **recommended** that despite higher initial capital costs, future designs of similar storage systems should incorporate insulated floors with thermostatically-controlled dampers (see model Section 7-4). This will permit more efficient control of indoor climate. The storage mass should also be adequately insulated on all sides to minimize heat loss to surrounding permafrost and/or air. The foundation could also be modified to improve venti**lation** by acting as an air warmer for conditioning incoming air.

3-4-3 SOLAR COLLECTOR

The late completion of the solar collector in August 1986 did not allow sufficient time to adequately assess its performance but a number of observations were recorded and are presented here.

The location of the collector panel on top on the greenhouse ensures an unobstructed exposure to the sun as it travels **in** the southern hemisphere. The panel represents an increase of **50%** in total absorbing surface area of the greenhouse and can be expected to contribute positively to overall energy balance. The greatest contribution of the **collector** to energy balance will likely occur in the spring at peak solar radiation levels (Section 3-3-3).

In a preliminary trial conducted at the end of September, the panel was extremely effective at absorbing radiation and heating the air. Temperatures in the panel were heated to 45°C within minutes of exPosure to bright **sunlight.** The fan activated and delivered the heated air into the heat storage foundation.

One major change to the system is recommended since in the springtime, the delivery of heated air into a frozen heat storage foundation would seem counterproductive. Therefore a thermostatically-controlled damper system should be installed on the delivery vent which could direct air from the collector directly into the greenhouse and contribute to warming it. Once desirable greenhouse temperature levels are attained the damper would close, delivering heated air to the foundation.

3-4-4 GREENHOUSE FRAME AND GLAZING

[A] Frame

The design of a straight-sided structure (as opposed to a curved or Quonset-type) permitted the installation of rigid insulating panels with high resistance values. In addition, conventional construction materials available in town (lumber, straight glass) could be easily used to repair any damage.

The use of wood in place of metal for the supporting structure may have advantages in the Arctic in terms of flexibility and shock resistance , where sub-zero temperatures make solids very brittle.

The insulated roof was likely responsible for a reduced heat loss from the greenhouse when compared to glazing alone. The roof area also provided a convenient base for the installation of the solar collector panels. Future designs may also benefit from a rooftop crawlspace to locate air-to-air heat exchangers and as a storage space for insulating thermal curtains or blankets.
The presence of a covered roof did not reduce the amount of direct sunlight striking the plants but it may have been responsible for a decrease in total illumination at certain times of the year, particularly in the fall months when conditions were overcast.

it is difficult to determine whether a glazed north-facing wall is beneficial or detrimental to an arctic greenhouse. In terms of illumination, the amount of direct sunlight entering the north side is small, but indirect light, particularly in the spring, may contribute significantly to greenhouse light levels. However, at other times of the year, such a large glazed area represents a substantial heat loss to the overall energy balance of the greenhouse. A solution to this problem may exist if an effective system of insulating curtains or shutters is designed which would permit the selective use of the north-facing glazing during certain seasons or times of day.

[B] Glazing

Based on the observations made in Pond inlet, The use of SDP acrylic glazing is strongly recommended for arctic greenhouses for a number of reasons:

[1] Strength - The acrylic Panels resist shocks and blows effectively even under cold conditions when panels are quite brittle. This feature would be particularly important in communities where vandalism is a potential problem. When breakage does occur, panels puncture instead of shattering and can be easily repaired with clear patching tape. The ribbed panels are also shipped more easily without the special treatment necessary for glass.

[2] Light Quality - Acrylic panels have a relatively high transmission value of 83% which is only slightly lower than glass in terms of quality and quantity for growth of vegetables. The insulating quality of double glazing reduces condensation and therefore increases light transmission.

[3] Insulation - The insulating air space (RSI=0.31) between the two layers of glazing reduces convective heat loss. The lower heat transfer coefficient of acrylic versus glass (3.29 vs 5.96) represents an estimated 45% in energy savings. The panels are also able to withstand at least a 40°C difference between indoor and outdoor temperatures.

[4] Durability - The expected life of good quality acrylic panels is in the range of 15-20 years in temperate climates. Decreased exposure to sunlight in the arctic may possibly extend this period (assuming panels are covered for 6 winter months). The glazing in Pond Inlet overwintered successfully (1985-86) and no damage to the panels occurred despite considerable ice buildup at the bases. Acrylic glazing requires a higher capital expenditure than conventional glass but it’s lighter weight makes freight costs much lower.

3-4-5 INSULATION, COVER AND AIRLOCK

[A] Insulation

The Thermax insulation was very effective in reducing heat loss from the greenhouse during the winter months. The panels were fitted tightly together providing a seal which virtually eliminated leakage into the greenhouse. The use of sealing tape effectively blocked small cracks. The foil backing of the panels contributed to improved illumination by reflecting light from the halide lamp down towards the growing beds and around the back sides of the hanging planters.

The large size and rigid construction of the panels made them awkward and cumbersome during installation and removal. In addition, an exterior storage space was required in the summer to accommodate their considerable volume. The difficulty of manipulating the panels meant that they could not be rapidly installed or removed to function as nighttime protection in spring and fail.

The challenge for operators of future arctic greenhouses lies in designing a thermal blanket/ panel/ shutter which is readily moveable, can be stored within the greenhouse structure and effectively dupl icates the high thermal resistance of the rigid panels used in Pond Inlet.

[B] Airlock

The airlock was an essential addition to the winterized greenhouse to decrease wind activity and reduce heat loss around the greenhouse door. It was however, too small to make access easy and should be modified.

In Pond Inlet, the construction of a walk-in corridor connecting the greenhouse and hotel would :

(a) provide an effective airlock an all seasons,

(b) allow easier access for workers and visitors in the cold months,

(c) contribute to ventilation by exchanging air with the hotel instead of outside.

[C] Canvas Cover

The black canvas cover which provided winter protection for the glazing had a low insulative value but did contribute to reducing cold air seepage into the greenhouse. In the early spring, sunlight falling on the black surface was absorbed, thus melting the snow and heating up the glazing and air on the outside of the insulative layer. The retractable flaps on the south facing side of the cover will permit the exposure of the solar collector to the sun early in the spring.

Future designs may consider an insulated exterior blanket with similar airtight qualities and protective features. An insulated layer may further reduce heat losses from the greenhouse. An easier system of installation and removal should also be designed.

3-4-6 VENTILATION

[A] Sumner Season

Ventilation provided by the passive vents was adequate in the summer and the operation of the collector fan improved air circulation in the greenhouse. The addition of an exhaust fan should improve the removal of excess heat in future seasons and draw fresh air into the greenhouse. The operation of an interior circulating fan is recommended on overcast days to promote adequate mixing of air.

[B] Fall and Winter Seasons

The original design of the greenhouse did not accommodate for its subsequent "winterization" and no effective air exchange or ventilation system was incorporated. This resulted in a number of problems including reduced circulation of air and pronounced stratification of temperatures, elevated humidity levels and cold air entry directly into the greenhouse. If effective production of crops is to be undertaken in future winter seasons, some system of air exchange must be installed.

A number of options are available to improve ventilation in the winterized greenhouses:

[1] The installation of an air-to-air heat exchanger would improve air exchange between the interior and exterior, reduce ventilative heat loss (thereby saving energy) and dehumidify greenhouse air. Heat exchangers function by transferring heat from outgoing to incoming air across thin metal channels. The efficiency of this exchange ranges from 30% (at -30°C and below) to 79% (at +10°C and above) and may represent a substantial savings in energy costs.

[2] Airlock or Conditioning System - Heat loss and cold air shock to plants may also be reduced by drawing cold outside air through a fan-driven conditioning system or separate airlock. The heat storage system can be modified to suit this purpose (Brace Research Institute, 1984).

[3] The installation of an insulated corridor between the greenhouse and an existing building (government office etc) would provide adequate ventilation for the greenhouse with a minimum amount of heat loss. As an added benefit, the greenhouse would supply the building with air high in humidity and oxygen. In the spring and Sumner, excess greenhouse heat could be vented to the building instead of outside. One disadvantage of such an arrangement is the increased likelihood of pathogen transmission to Plants.

3-4-7 HEATING AND LIGHTING

[A] Heating System

The **glycol** radiator was effective as a unit heater in providing supplementary heat to the greenhouse. The use of a blower fan permitted rapid emission of heat into the greenhouse which contributed to air circulation in the process. The unavailability of an on-line **programmable** thermostat prevented the setting of separate day and night temperatures (available only for low-voltage central heating systems) . This meant that settings had to be changed manually which was at times an unreliable method.

The possibility of sharing heating resources with other buildings should be considered for northern greenhouses as a means of reducing capital costs. Waste heat must also be thoroughly examined as a cheaper alternative to conventional fuel-based systems.

[B] Lighting Systems

The metal halide lamp was not as effective in supplying adequate illumination as originally expected. It did provide good quality lighting but only for an estimated 5-7 m2 of growing bed and the level of illumination in the corners of the greenhouse was too low for vegetable production. The lamp was very effective in supplying light to the hanging planters and all tomatoes and cucumbers thrived. This was in part due to the enhanced thermal climate in the upper half of the greenhouse where temperatures were warm and colder air drained away.

The lamp and ballast did supply a great deal of heat and were easily stored when not in use. The use of 2 or 3 sodium lamps (HID) in the place of the halide would provide a more even distribution of light without increasing the electrical load by more than 20X.

A NOTE CONCERNING AUTOMATION

The design and use of fully-automated systems for the control of greenhouse climate is highly recommended. In Pond Inlet, the lighting systems were independently controlled by timers, and heaters and venting units by temperature-controlled thermostats. These controls are more reliable, provide a more uniform growth climate, reduce the need for daily surveillance and allow the technician a greater flexibility in working hours.

In recent years, sophisticated computer software for monitoring and controlling greenhouse environments has been developed (Priva, DGT) This is an important step towards optimizing growing conditions within greenhouses and should be thoroughly investigated for use in future northern greenhouses.

SECTION 4: PLANT PERFORMANCE AND GROWTH SYSTEMS

This section (a) summarizes the methods used for vegetable production in each of the growth systems tested, (b) presents the yields and performance of 65 selected vegetable varieties grown in 1986 and (c) evaluates the different vegetable production systems tested.
A more detailed account of systems operation and vegetable production techniques including sources of equipment can be obtained from the greenhouse operating manual" Pond Inlet Gardens Greenhouse Operating Manual ", Romer, 1987.

4-1 GROWING PROCEDURES

4-1-1 SOIL CULTURE

[A] Greenhouse

Soil-based plants were grown in wooden beds (Section 2-3-3) and hanging planters in 1986.
Seeds were germinated in one of two types of media:

1. Jiffy 7 peat pellets were used for cucumber, green pepper and tomato seedlings.

2. Seedling soil mix was used for all remaining varieties. Plastic Cell-Paks (tin) and styrofoam cups were used as containers. The soil mix was formulated using :
   1 part local soil
   (sand 1:2 peat)
   2 parts Redi Earth *(tin)*
   1 part Vermiculite
   1 part Perlite (tin)

Seedlings were grown for various lengths of time before transplanting into the soil beds. Leafy crops such as lettuce, spinach and chinese cabbage required only two weeks pre-growth while tomatoes and cucumbers needed 4-6 weeks. In the summer season, seedling trays were located on top of one of the gravel hydroponic beds (Photo 8).

Transplantation of seedlings into the soil beds was done on overcast cool-weather days to reduce shock and subsequent setback in growth. In 1986, the variety, selection and placement *of* vegetables in the soil beds was a balance between suitable companion planting, soil requirements and aesthetic appearance.

[B] Cold Frame Gardens

Vegetables grown in the outdoor cold frames were initiated from seeds sown directly in the soil beds without the benefit of an indoor pre-growth period. Seeds were planted on July 5 and germination occurred in most cases after 2-5 days. Most crops were harvested in the first week of September after a total of 8-9 weeks growth. Similarly, seed potatoes were dug directly into soil in the uncovered 45-gallon drums on July 1st and left to germinate.

[C] Regular Maintenance

Indoor and outdoor soil beds were routinely fertilized every 14 days with "Plant Prod" fertilizers:

1. 'Starter'[a] 10-52-10 - for seedlings every 2 weeks
   (5 mls/litre) and at transplant
2. "All-Purpose" 20-20-20 - for leaf crops
   (4 mls/litre)
3. 'Vegetables" 15-15-30 - for leaf and fruit-bearing
   (3.5 mls/litre) crops

Water was supplied as needed to all soil beds.

4-1-2 NFT HYDROPONIC CULTURE

Presently, one of the principle problems with NFT hydroponic culture is the lack of suitable methods for establishing young plants in the gutters. Seedlings lack self-support prior to development of a root mat and their ability to acquire oxygen from solution is also limited. A number of different methods for seedling suPport were tested in preliminary crop trials in Pond Inlet:

1. <u>Rockwool-filled plastic cell packs</u>
   with perforated sides and bottom. Seedlings were inserted in the fibrous wool but did not develop an adequate root mat and the waterlogged wool resulted in the death of plants, probably due to inadequate aeration and rotting of roots.

2. <u>Soil-filled plastic cell packs</u>
   with perforated sides and bottom. These containers worked well but leaked a great deal of debris into the gutters which plugged the filters and necessitated frequent cleaning of the system.

3. 'Jiffy 9" peat pellets
were very effective as a support medium, producing virtually no debris and allowing plant roots to exit freely. A system was developed and used throughout 1986 which further improved seedling establishment and growth following transplant into the NFT gutters.

The "Jiffy 9" pellets were seeded and arranged on top of a bed of moist sand (8mm) in a tray then placed 10cm below a bank of neon lights for 2 or 3 weeks (Figure 5). Seedling roots grew from the pellet into the moist sand and developed a small 'root mat". At transplanting time the soil was thoroughly soaked to remove pellets from the trays and attached roots were gently washed free of sand. The plants transferred in this manner benefitted from a pre-developed root mat and quickly adapted to NFT conditions.

In order to simplify maintenance, the nutrient solution was formulated from a commercially-available mix (18-9-27 at 5mls/litre) sold by Hydroponic of Montreal. The solution was changed at two week intervals and maintained at a constant volume in the reservoir between solution changes by the addition of water (no additional nutrients).

pH and conductivity were measured several times per week using a Hydec digital conductivity, temperature and PH meter. pH of the solution was maintained between 5.8 and 6.8. Phosphoric Acid was used to decrease PH and Sodium Bicarbonate was used to raise PH levels.
Following harvest of each crop of mature plants, the gutters were cleaned of debris and new seedlings introduced.

4-1-3 GRAVEL HYDROPONIC CULTURE

Since the problem of suPport for Young seedlings is eliminated in gravel culture beds, seedlings in this method were grown in vermiculite until they developed a sufficiently large root network to permit transplanting into the gravel . At transplant time, the vermiculite was washed from the roots and the seedlings were inserted into the gravel medium. The nutrient solution was continuously circulated and allowed to trickle past the roots in the medium. The mixing and regulation of the nutrient solution was the same as for the NFT bed (Section 4-l-2).

4-2 PERFORMANCE AND PRODUCTION OF VEGETABLES

4-2-1 SELECTION OF VARIETIES

A number of criteria were used when selecting varieties to be tested in the Pond inlet greenhouse :

[1] Varieties previously tested in other arctic projects and **recommended** for northern cl**imates.** These include varieties tested at the Keewatin Gardens (Univ. of Toronto 1979-83), Agriculture Canada research stations in Fort **Chimo** and **Inuvik** (Section t-2-t) and those **recommended** by **R.E.** Harris in 'Northern Gardening" (1976).

[2] Varieties considered to be cool weather crops possessing frost tolerance and high productivity under cool weather conditions.

[3] Varieties having resistance to bolting (going to seed) . Long photoPeriod and high daytime temperatures contribute to early bolting of many southern varieties in arctic greenhouseS.

[4] Varieties having short maturation times, above average yields and the capacity to grow in crowded conditions (container varieties).

The list of varieties tested in 1986 is presented in Table 7. **Many** varieties of several Kinds of vegetables were tested in **both** soil and hydroponic systems in order to find the most suitable varieties and expand the **recommended** 1ist for use in northern projects.

The varieties were rated on the basis of several criteria:

1. Growth and **developm**ent - adaptabi**lity** to greenhouse conditions, resistance to bolting, adaptability to hydroponic culture (development of root mass, leaf qual**ity).**
2. Productivity - overall yield in **small** area and relative yield in comparison to other varieties tested.
3. Quality of Produce - appearance, texture and taste of harvested Produce.

TABLE 7 : List of vegetable varieties tested in Pond Inlet.
(**** = Highly **Recommended** ; *** = **Recommended**)
(NR = Not **Recommended** ; NS = Not Successful in 86)

VARIETY TESTED	**GH** SOIL BEDS	**GH** NFT HYDROPONICS	COLD **FRAMES**
BEAN :			
Strike	●***		
BEET :			
Baby Badger			NS
Detroit Dark Red	●***		NS
Early Red Ball			NS
Little Egypt	NR		NS
Ruby Queen			NS
CARROT :			
Golden Ball	NS		
Touchon	NS		
CHINESE CABBAGE :			
Chihili			●**
Hybrid China King		NS	●**
Hybrid Jade Pagoda	●***	****	****
Pe Tsai		NS	●**
Springtime			●***
Hybrid Two Seasons			***
CUCUMBER :			
Bush Crop	NR		
Pot Luck	****		
KALE :			
Dwarf Scotch Kale	NR		NS
Tall Scotch Curled	●E*	***	NS
LETTUCE :			
Buttercrunch (bibb)	●**		
New York # 12 (head)	NR	***	
Grand Rapids	●E**	●**E	
GR Dark Green		●*a*	NS
GR Tip Burn Tolerant		***	
Green Ice		***	NS
Prizehead		NR	
Ruby Red	NS	****	NS
Red Sails		●***	NS
Salad Bowl		***	NS
Simpson	****	****	
Black Seeded Simpson	***	NR	NS
Slobolt	NR	NR	NS
Waldmann's Dark Green **MI**		NS	
White **Cos** (romaine)	●*X		
Paris White **Cos**		N**	

TABLE 7 cent'd

VARIETY TESTED	GH SOIL BEDS	GH NFT HYDROPONICS	COLD FRAMES
KOHLRABI :			
Early White Vienna	NR		
ONION :			
Dutch sets	***		●S**
Multipliers	***		●***
SNAP PEAS :			
Dwarf Melting Sugar	NR		
Little Sweetie	NR		
GREEN PEPPER :			
Superset	NS		
POTATO :			
Chieftain			NS
RADISH :			
Champion			***
Cherrybelle	NR		****
Comet			●**
Early Scarlett Globe	NR		NR
French Breakfast			●**
Saxa			****
Snowbelle			●Z**
Sparkler White Tip			***
SPINACH :			
Cold Resistant Savoy	NR		●E**
Long Standing Bloomsdale	NR		****
Melody	NR		****
Tyee			****
SWISS CHARD :			
Fordhook Giant	***	NR	
Burgundy Crimson	***	NR	
Silver Giant	●**		
SQUASH :			
Zucchini	****		
TOMATO :			
Tiny Tim (cherry)	***		
Toy Boy (mid-size)	****		
Early Salad	****		
Burpee's Pixie Hybrid	****		
Sub Arctic Maxi	****		
Patio	●S*		
Vendor	****		
TURNIP :			
Purple ToP White Globe	●*R*		

Varieties were rated as follows:

xxxx	Highly recommended	- demonstrated good growth and productivity in 1986.
xxx	Recommended	- growth was adequate, performance and productivity showed potential for improvement in better seasons.
NR	Not recommended	- unfavorable growth and performance in system tested.
NS	Unsuccessful test	- performance of tested variety could not be adequately assessed and will not be rated (due mainly to unsuitable growth conditions) .

4-2-2 LIMITATIONS TO PRODUCTIVITY

The phonological development and freshweight yields of the vegetable varieties tested in 1986 are presented in Figures 18, 19, 20 and Tables 8, 9 and 10. When examining this data it is important to consider the following factors which influenced potential productivity.

[1] Lack of Monoculture

Most commercial greenhouses grow only 1 or 2 varieties at a time and growth conditions are "tailored" to meet the specific needs of those varieties (ie optimum day-night temperature, humidity and light requirements). In Pond Inlet however, field and greenhouse cultivars were grown simultaneously in the greenhouse in order to maximize the amount of information obtained from variety trials. Conditions could not be optimized for each specific variety; instead an effort was made to provide suitable conditions for the majority of plants.

[2] Uncharacteristic Season

The climatic conditions experienced in 1986 were less favorable to production than can normally be expected for this area. Temperatures were low and sunlight hours fewer than may be expected for an average year (Section 3-l).

[3] Incomplete Systems

The control systems which regulate greenhouse climate were not fully operational throughout the 1986 season. Equipment was being installed and tested as the growing trials were in progress. This resulted in increased temperature fluctuations, stratification of greenhouse temperatures and inadequate ventilation and gas exchange.

[4] Shading

The shading of the greenhouse by the hotel (discussed in Section 3-2) substantially reduced the light available to plants in some beds and most probably affected growth and productivity.

These factors combined to create sub-optimal growing conditions for vegetables tested in 1986. It is expected that given average macroclimatic conditions and a properly controlled and fully operational greenhouse, plant productivity may be expected to increase considerably in future growing seasons.

4-2-3 EVALUATION OF VEGETABLE VARIETIES

The primary focus of this section is to establish the horticultural feasibility of cultivating tested varieties in the arctic. The analysis and determination of economic viability is presented in Section 5.

The following analyses are based on the data presented in Figures 18, 19, 20 and Tables 7, 8, 9 and 10. The individual varieties have been numbered to facilitate their location on the tables and figures.

The number of estimated crops Per year is based *on* the duration of time the crop occupies the growing facilities (estimated from transplant of seedlings (t) to harvest, not seed germination to harvest (Figures 18, 19, 20)).
A total of 65 varieties of 18 different vegetable cultivars were tested in 1986.

BUSH BEAN

Bush beans demonstrated good growth in the greenhouse soil beds under both summer and winter conditions. Pods were long (15cm), crispy and sweet, making them a favourite vegetable of local visitors (Photo 14). Yields of Strike beans (1) averaged 4.18 kg/m2 in the summer, almost 3.5 times greater than field-grown southern crop estimates (1.22 kg/m2, Resh, 1985). Yields of crops planted in the winter (2) were considerably lower (1.69 kg/m2) but the fruit quality remained high. An average of 6 crops could be expected per year.
The year-round production of beans in northern greenhouSeS is horticulturally feasible but the greatest success may be expected during the spring and summer seasons when natural sunlight is available. The possibility of outdoor cultivation in cold frame gardens should be investigated as this vegetable is popular with local residents.

TABLE 8 : Freshweight yields and cultivation densities of vegetable varieties tested in greenhouse soil beds.

ID #	VARIETY		DENSITY #/m2	YIELD Kg/m2
1	BEAN	Strike	24	4.18
2		Strike	24	1.69
3	BEET	Detroit Dark Red	60	6.17
4		Little Egypt	60	1.67
5	CARROT	Touchon	120	1.02
6		Golden Ball	120	0.94
7	CHINESE CABBAGE	Jade Pagoda	40	9.44
8	CUCUMBER	Pot Luck	27	14.85
9		Pot Luck	27	11.88
10		Bush Crop	27	5.04
11	KALE	Dwarf Scotch	60	1.72
12		Dwarf Scotch	60	0.70
13		Tall Scotch Curled	60	4.06
14		Tall Scotch Curled	60	2.47
15	KOHLRABI	Early White Vienna	40	4.12
16	LETTUCE	Buttercrunch	60	4.56
17		New York #12	60	4.55
18		Grand Rapids	60	6.78
19		Ruby Red	60	2.42
20		Simpson	60	6.42
21		Black Seeded Simpson	60	4.08
22		Slobolt	60	3.00
23		White Cos	60	3.56
24	ONION	Dutch Sets	120	1.09
25		Multipliers	120	3.00
26	PEAS	Dwarf Melting Sugar	60	0.82
27		Dwarf Melting Sugar	60	1.16
28		Little Sweetie	60	0.26
29	PEPPER	Superset	10	--
30	RADISH	Cherrybelle	240	2.40
31		Early Scarlett Globe	240	2.88
32	SPINACH	Melody	60	0.82
33		Cold Resistant Savoy	60	0.60
34		Long Standing Bloomsdale	60	0.55
35	Swiss CHARD	Fordhook Giant	60	2.15
36		Burgundy Crimson	60	3.22
37		Silver Giant	60	2.61
38	SQUASH	Zucchini	4	2.00
39	TURNIP	Purple Top White Globe	24	8.39
40	TOMATO	Patio	10	4.56
41		Sub Arctic Maxi	10	13.02
42		Toy Boy	10	5.05

FIGURE 18 : **Phenological** development of vegetable **varieties** tested in greenhouse soil beds.

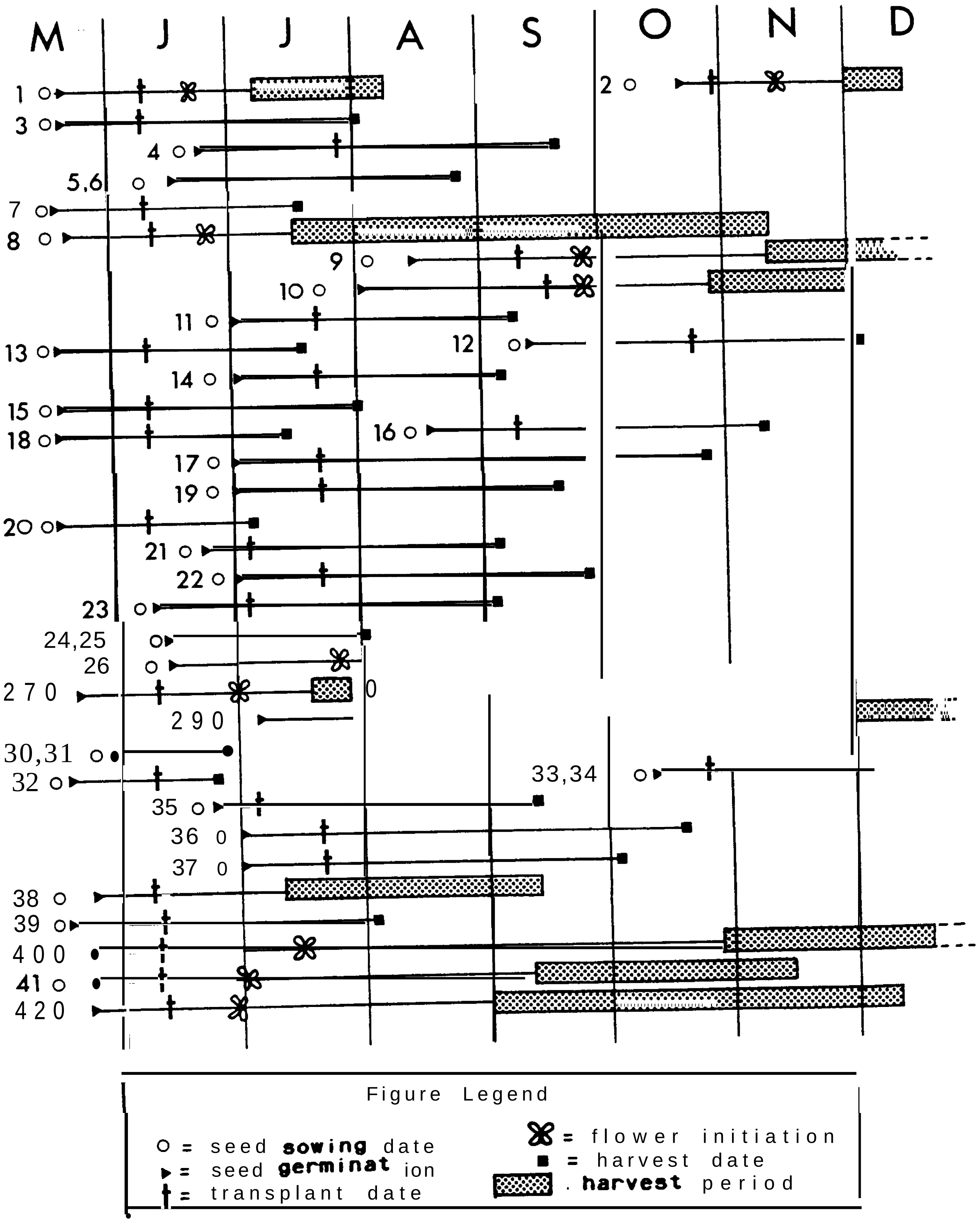


TABLE 9 : Freshweight yields and cultivation densities of vegetable varieties tested in hydroponic culture.

ID #	VARIETY		DENSITY #/m2	YIELD kg/m2
43	CHINESE CABBAGE	Jade Pagoda	40	4.80
44		Hybrid China King	40	1.04
45		Pe Tsai	40	0.96
46	KALE	Tail Scotch Curled	50	2.50
47	LETTUCE	New York # 12	60	4.94
48		Grand Rapids	60	5.67
49		Gr Rap Dark Green	60	8.34
50		Gr Rap Dark Green	60	2.20
51		Gr Rap Tip Burn Tolerant	60	2.78
52		Green Ice	60	4.42
53		Green Ice	60	1.42
54		Prizehead	60	2.21
55		Ruby Red	60	5.71
56		Ruby Red	60	1.86
57		Red Sails	60	5.05
58		Red Sails	60	5.08
59		Salad Bowl	60	7.03
60		Simpson	60	6.00
61		Black Seeded Simpson	60	2.69
62		Slobolt	60	2.07
63		Paris White Cos	60	5.99
64		Waldmann's Dark Green MI	60	1.55
65	SPINACH	Melody	60	0.68
66	Swiss CHARD	Fordhook Giant	60	--
67		Burgundy Crimson	60	--

TABLE 10 : Freshweight yields and cultivation densities of vegetable varieties tested in outdoor cold frames.

ID #	VARIETY		DENSITY #/m2	YIELD Kg/m2
68	BEET	Detroit Dark Red	60	0.49
69		Ruby Queen	60	0.68
70		Little Egypt	60	0.61
71		Early Red Ball	60	0.50
72		Baby Badger	60	0.65
73	CHINESE CABBAGE	Jade Pagoda	40	2.50
74		Hybrid China King	40	2.38
75		Pe Tsai	40	2.68
76		Springtime	40	3.04
77		Two Seasons	40	2.31
70		Chihili	40	0.91
79	KALE	Dwarf Scotch	60	0.53
80		Tall Scotch Curled	60	0.56
81	LETTUCE	Grand Rapids Dark Green	60	0.56
82		Green Ice	60	0.49
83		Ruby Red	60	0.46
84		Red Sails	60	0.64
85		Salad Bowl	60	--
86		Black Seeded Simpson	60	1.01
87		Slobolt	60	0.42
88	ONION	Multipliers	120	3.30
89	POTATO	Chieftain	10	--
90	RADISH	Cherrybelle	240	3.14
91		Early Scarlett Globe	240	1.27
92		Champion	240	2.52
93		Comet	240	2.42
94		French Breakfast	240	2.62
95		Snowbelle	240	2.90
96		Saxa	240	2.62
97		Sparkler White Tip	240	2.26
98	SPINACH	Cold Resistant Savoy	60	1.34
99		Long Standing Bloomsdale	60	1.41
100		Melody	60	1.24
101		Tyee	60	1.38

FIGURE 19 : Phonological development of vegetable **varieties** tested in NFT hydroponic culture.

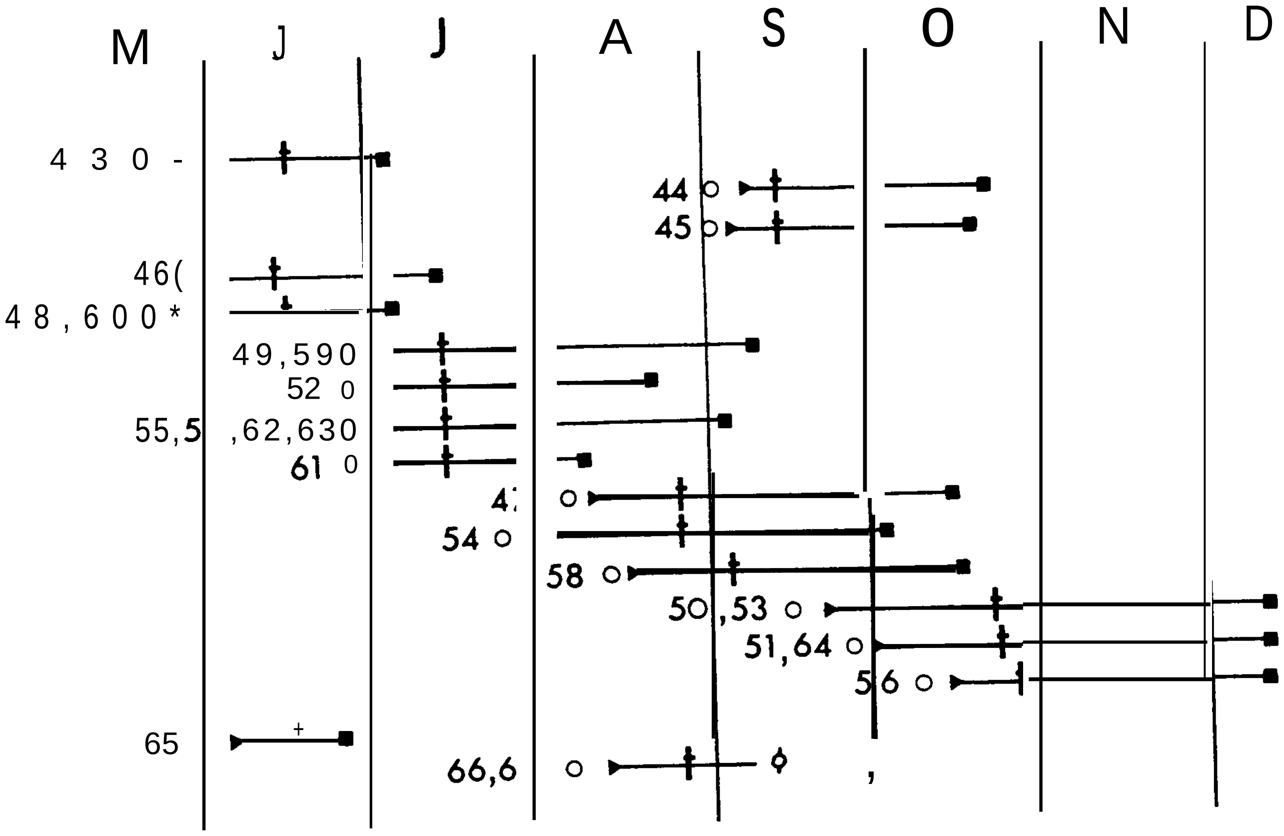


FIGURE 20 : phonological development of vegetable varieties tested in outdoor cold frames.

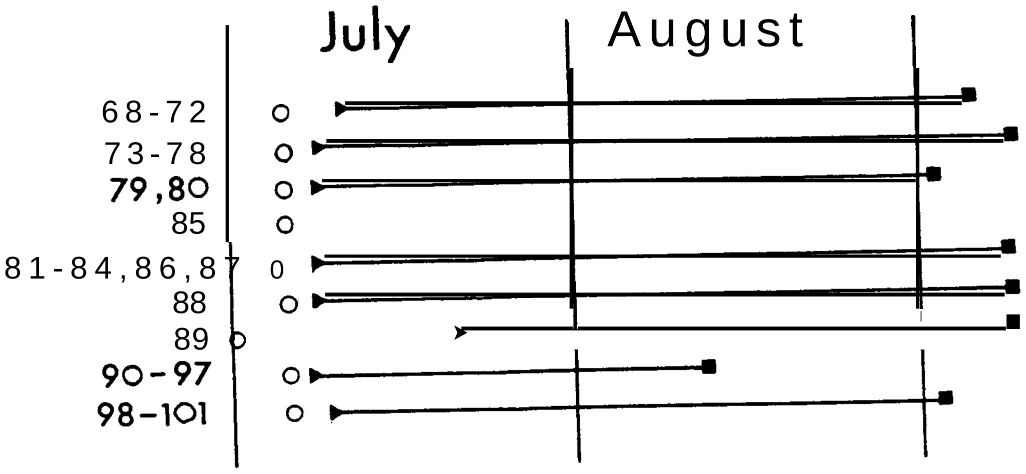


Figure Legend

o = seed **sowing** date
▶ = seed germination
† = transplant date
✻ = flower initiation
■ = harvest date
▨ = harvest period

BEET

Beets were grown primarily for their leaves which make nutritious salad greens in the summer season. Detroit Dark Red beets (3) planted in greenhouse soil beds produced large leaves of good flavour and medium-sized roots with combined yields averaging 6.17 Kg/m2 (Photo 16). This figure is over 6 times greater than southern field crop estimates (1.0 kg/m2, Resh, 1985). An average of 6 crops of beet tops may be produced annually. The cultivation of Little Egypt was not successful in 1986.

In contrast to the greenhouse, all beets grown in outdoor cold frames (68-72) were slow-growing and produced insignificant yields. Previous success with outdoor cultivation of beets in Rankin Inlet where yields for Detroit Dark Red averaged 6.8 kg/m2, suggests that the poor 1986 climate in Pond Inlet was responsible for low yields.

The production of beets may be considered for northern soil-based greenhouses and cold frames but production levels should be dictated by market demand as exposure to this vegetable (particularly the use of greens) has been minimal. The use of transplants is strongly recommended to improve yields in outdoor cold frames.

CARROT

The carrot varieties Touchon (5) and Golden Ball (6) were slow to germinate and develop in the greenhouse soil bed due mainly to inadequate spacing and shading by neighboring plants. Roots at harvest were small and well below marketable size although the miniature variety Golden Ball is usually easily grown in shallow soils.

Despite the lack of success in 1986, the commercial production of carrots should not be discouraged before additional trials are conducted since carrots have an established popularity in the north and represent 11% of the current vegetable consumption in Pond Inlet. Their low retail value and good storage potential better suit them to outdoor cold frame cultivation and future trials should examine growth in these conditions.

PHOTO 12 : Tomatoes, variety _Tiny_ **_Tim_**, ripening on vine in greenhouse. November, 1986 (top left).

PHOTO 13 : Cucumbers, variety _Pot Luck_, growing in hanging planter (right).

PHOTO 14 : Green Bush Beans, variety _Strike_, on display. (bottom left)

CHINESE CABBAGE

Chinese cabbage was successfully grown in all systems tested. This cool weather crop is particularly suited to outdoor culture in the arctic, and cold frame yields were the highest of all 8 vegetables tested outdoors. Springtime (76), Pe-Tsai (75) and Jade Pagoda (73) were the most productive varieties in the cold frames, yielding between 2.38 and 2.68 kg/m2. These values are only 16% of yields obtained in Rankin Inlet (16.8 kg/m2) and should increase substantially in better seasons.

Inside the greenhouse, Jade Pagoda (7,43) was grown in the summer in both soil and NFT hydroponic beds. Yields were much greater than those in outdoor facilities, averaging 9.44 and 4.80 kg/m2 respectively (Photo 15). Maturation time of plants in NFT beds (19 days post transplant) was only half of that for plants in soil beds (38 days post transplant). Plants adapted easily to hydroponic culture, producing large root mats and sturdy shoots, and in all growing beds produced crispy succulent shoots with a sweet flavour. This new variety proved to be a favourite of local residents.

Attempts to grow chinese cabbage in the fall (China King (44), Pe-tsai (45)) were unsuccessful due to an infestation of aphids and further trials would be necessary to assess performance under artificial lighting. The spring and summer cultivation of this fast-growing crop is highly recommended for both indoor and outdoor conditions.

Although there has been no exposure to this vegetable in northern communities, its similarity to lettuce in flavour and usage should heip accelerate its acceptance as a stapie vegetable.

CUCUMBER

The testing of cucumbers was i imited to two varieties grown in soi i-fi i led containers. Pot Luck (8,9) is a small bush hybrid which produced sturdy 40-70 cm vines with a high degree of flowering and a steady supply of fruits over a 4-month period. The cucumbers were 15-20 cm long, crispy and of exceptional flavour (Photo 13). Pi ants of this variety aiso responded well to winter conditions but floweredless.

Yields of Pot Luck averaged 14.85 kg/m2 for the summer crop and 11.88 kg/m2 for the winter crop (harvest incomplete). Assuming an average of 2 crops Per year, the annualyield can be estimated at 29 kg/m2 or comparable to the Canadian average of 27 kg/m2 (Statistics Canada, 1977).
The growth of the variety Bush Crop (10) proved unsuccessful in 1986 due primarily to an unfavourablelocation beside the glazing.

Cucumber production is highly **recommended** on a year-round basis for northern greenhouses. The plant's vertical growth habit provides a high yield per unit of growing area and the long crop season reduces **labour** requirements. Cucumbers are currently being successfully produced under hydroponic culture in many southern regions and this possibility should be thoroughly investigated and considered for future northern projects.

KALE **(Borecole)**

Kale was not a very successful crop in 1986. Plants grown from seed in the outdoor cold frames (79-80) produced negligible yields (0.53-0.56 **kg/m2)**, although cold frame yields of kale averaged 7.5 **kg/m2** in **Rankin** Inlet (1982).

Overall productivity and Performance increased inside the greenhouse where kale was grown in soil and hydroponic culture (Photo 15). Yields were greatest for **TallScotch** Curled (13,46) which averaged 4.06 **kg/m2** (38 days post transplant) in soil and 2.50 **kg/m2** (30 days post transplant) in the NFT hydroponic beds in the **summer** season. Growth was slower and yields greatly reduced in the fall and winter (2.47 **kg/m2)** when light **levels** decreased but plants adapted well to all conditions. Yields of Dwarf Scotch (11,12) were lower (0.70-1.72 **kg/m2)** and plants adapted less **favourably** to greenhouse conditions.

Kale is a member of the cabbage family that has received **little** exposure in northern **communities**. Its **flavour** and methods of preparation are similar to cabbage and it requires a shorter season to mature. The production potential of this **cultivar** will hinge uPon consumer acceptance and market value. For the present, a limited seasonal production in outdoor cold frame gardens is recommended to increase the local exposure to this nutritious vegetable.

KOHLRABI

Kohlrabi like kale, is well suited to northern regions and the variety Early White Vienna has been successfully grown outdoors in **Rankin** Inlet where yields averaged 8 **kg/m2**. In **summer** 1986, kohlrabi was grown primarily for its edible cabbage-like leaves. Growth was slow however, and yields of Early White Vienna (15) were only 4.12 **kg/m2** after 52 days in the greenhouse soil beds.
As a result, this variety can only be **recommended** for **limited** outdoor production in cold frames until consumer demand and market value can be more adequately assessed.

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LETTUCE

Lettuce was the most thoroughly tested greenhouse crop in 1986. Emphasis was placed primarily on leaf varieties as opposed to head lettuce because of their more rapid growth and greater ease of production.

[A] Cold Frame Gardens

All varieties of leaf lettuce (81–87) grown from seed in outdoor beds were completely unsuccessful due to unfavorable growth conditions. Black Seeded Simpson (86) was the hardiest and most productive of the 7 varieties tested, with very low yields of 1.0 Kg/m2 (Photo 20). Other plants were very small and not marketable. Under more favorable conditions in 1982, lettuce productivity in Rankin Inlet cold frames reached 9 Kg/m2 for Grand Rapids.

[B] Greenhouse Soil Beds

Lettuce grown in soil beds did well in summer trials. Yields of Grand Rapids (18) and Simpson (20), harvested 34 and 25 days after transplant, averaged 6.78 and 6.42 Kg/m2 respectively, and were the highest of the 4 varieties tested. Plant shoots were tall with no tip burn evident or bitterness in taste (Photos 15,16). Yields of Black Seeded Simpson (21) and White Cos (23) were lower averaging 4.08 and 3.56 Kg/m2 respectively over a 2-month cultivation period from transplant to harvest.
All lettuce plants grown in the summer began bolting after 4-6 weeks and were harvested at that time. This reduced the length of the cultivation period and therefore the potential productivity of plants.

Fall lettuce crops grew more slowly and yields were lower than in summer trials partially due to an aphid infestation which necessitated an early harvest. The most successful variety tested at this time was the Bibb type Buttercrunch with a freshweight of 4.56 Kg/m2 (60 days post transplant). Plants of New York #12, Ruby Red and Slobolt demonstrated poor growth in the fall and are not recommended.

[C] Greenhouse Hydroponic Beds

Most of the lettuce grown in 1986 was produced in the NFT hydroponic bed where a total of 16 varieties were tested over 3 seasons (Figure 19). In the first trial in June, Simpson (60) and Grand Rapids (48) varieties performed exceptionally well yielding 6.00 and 5.76 Kg/m2 respectively in only 3 weeks of hydroponic growth. Some shoots began bolting to seed in response to the high daytime temperatures experienced on sunny days.

A second trial conducted in July and August compared the suitability and productivity of 8 varieties of leaf lettuce (Photo 17). The performance of the romaine variety Paris White Cos (63) (5.99 kg/m2) (Photo 18), both red leaf varieties, Ruby Red (55) (5.71 kg/m2) and Red Sails (57) (5.05 kg/m2), and green leaf varieties Grand Rapids Dark Green (49) (8.34 kg/m2) and Salad Bowl (59) (7.03kg/m2) was outstanding. The other varieties tested may have grown better in less crowded conditions.

As in the soil beds, lettuce performance decreased in the fall and winter hydroponic trials. Growth was reduced in response to poor lighting conditions and inadequate ventilation. The most successful varieties in those seasons were Red Sails (58) yielding 5.08 kg/m2, New York #12 (47) at 4.94 kg/m2 and Grand Rapids Tip Burn Tolerant (51) at 2.78 kg/m2. Varieties of Slobolt (62), Waldmann's Dark Green MI (64) and Prizehead (54) were unsuccessful at this time.

in summary, lettuce is well suited to hydroponic and soil culture and may be strongly recommended for year-round production. An estimated 6-7 crops could be produced annually in the greenhouse if seedling transplants are used (possibly more in hydroponic culture).

GREEN ONION

Green onions were easily grown from sets in both greenhouse and cold frame soil beds over a 6 week period in the summer season. Both Dutch sets (24) and multiplier (25,88) onions were grown. Yields of multipliers were similar in soilbeds, averaging 3.00 kg/m2 inside and 3.30 kg/m2 outside the greenhouse (Photos 16 and 20).

The production of regular onions was not investigated but should be addressed by future projects as this vegetable currently represents 21% of imported produce in the community.

SNAP PEA (Edible-Podded)

Peas were tested as border plants to utilize some of the wall space in the greenhouse. Plants of Dwarf Melting Sugar (26,27) and Little Sweetie (28) grew very slowly in summer trials and Produced very low yields. This vegetable is of little importance in the northern market and is not recommended for indoor or outdoor production.

PHOTO 17 :

Leaf lettuce varieties in NFT hydroponic bed (left). (L-R) Salad Bowl; Grand Rapids Dark Green; Ruby Red; Paris White Cos; Slobolt; Green Ice; Red Sails.

PHOTO 18 :

Romaine lettuce var. Paris White Cos growing in NFT hydroponic gutter. Plastic cover is lifted to display root mat extending from the Jiffy 9 peat pellet.

PHOTO 19 :

Horticultural trainee Asenath **Pitseolak** **displaying** radishes grown in outdoor cold frames.

PHOTO 20 :

Outdoor cold frame. August, **1986.** (Left to right) Lettuce Grand Rapids Dark Green; Ruby Red; Green Ice; Black Seeded Simpson and **multipl**ier onions.

GREEN PEPPER

Only one variety of sweet pepper, Superset (29) was tested in containers in 1986. Data was not sufficient to adequately assess the performance and productivity of this vegetable but as green peppers are in demand in northern markets, additonal testing is recommended.

POTATO

The outdoor growth of potatoes in uncovered 45 gallon drum halves was not successful in 1986. A late snowmelt and lingering frost delayed the planting of tubers by almost 3 weeks. Potatoes responded unfavorably to the damp, cool and overcast conditions, taking almost one month to produce above-ground shoots. An examination of plants at the end of August revealed no appreciable development of tubers and the trial was considered a failure.

Despite this, the potential for outdoor arctic cultivation of potatoes has been demonstrated in trials conducted by the University of Toronto at Alexandra Fiord in 1982-84 (Bergsma, 1986). Yields of potatoes grown on the tundra under fabrene domes averaged 4.53 kg/m2 over 3 seasons, or just over 300 g per plant. Annual averages fluctuated between 200 and 375 g per plant which clearly illustrates the differences in yield which may be expected from season to season.

The seasonal cultivation of potatoes in large-scale outdoor facilities should be considered if economically viable.

RADISH

All radish varieties tested in outdoor cold frames matured successfully despite the poor conditions. Radishes produced large, juicy and crispy roots in just over 1 month from seed (Photo 19). Shoots showed no signs of bolting. The best quality and productivity were observed in the red-skinned varieties Cherrybelie (90) and Saxa (96) and in the white radish Snowbelle (95). Also of good quality were French Breakfast (94), Comet (93) and Champion (92). Yields of these 6 varieties ranged from 2.42 to 3.14 kg/m2 (approx. 240 units/m2) which compared favorably with averages obtained in Rankin Inlet [3.0 kg/m2).

Radishes grown indoors tended to bolt rapidly to seed before any substantial root production had occurred.
This vegetable is highly recommended for outdoor production during the summer months but is not a suitable candidate for indoor production.

SPINACH

Spinach plants are well suited to cool weather growing conditions and rapidly bolt in elevated greenhouse temperatures. All varieties tested in the greenhouse in summer began flowering before any substantial leaf mass was accumulated. Plants of **Melody** (65) adapted well, however, to hydroponic culture, developing an adequate root mass and maintaining a healthy appearance.

All 4 varieties tested (Cold Resistant Savoy (98), Long Standing Bloomsdale (99), Melody (100) and Tyee (101)) produced similar low yields in outdoor cold frames (l.24-1.41 **kg/m2)** but the **quality** of plants was exceptional with thick, juicy leaves and a very sweet **flavour.** In better years, yields of spinach may increase to over 4 **kg/m2** as demonstrated in **Rankin** Inlet between 1979 and 1982.

The cultivation of spinach is highly recommended for **summer** outdoor cultivation. The scale of operation will be dictated by consumer demand as this vegetable has not yet been tested in many northern **communities.**

SWISS CHARD

Swiss chard is a heat-tolerant relative of spinach that is more suitable for greenhouse production than its **cool-**weather cousin. The varieties Fordhook Giant (35), Silver Giant (37) and Burgundy Crimson (36), appeared healthy but grew slowly in the greenhouse and productivity was very low (2.15-3.22 **kg/m2)** considering the long period (2.4-2.9 months) spent in the soil beds. The attempt to grow chard in the hydroponic bed was completely unsuccessful .
Swiss chard grown outdoors in **Rankin** Inlet **yielded** 7.6 **kg/m2** over a two month growing season.

Although this vegetable is unknown to most northern consumers, it is a suitable **cultivar** for arctic regions and should be considered for further horticultural trials and market research.

SUMMER SQUASH (Zucchini)

Zucchini squash (38) was successfully grown in the greenhouse in the summer season. Fruits were of good **quality, averaging 18-20** cm in length and up to 250 grams each. Growth was unfortunately **l**imited by overcrowding in the **soil** beds and an adequate assessment of total possible **production** could not be made.
Sumner squash was previously grown with success in cold frame trials in **Rankin** Inlet. The cultivation potential of this vegetable in less crowded outdoor facilities should be assessed as a more economical alternative to greenhouse beds.

SUMMER TURNIP

Turnips were successfully grown in the greenhouse in the summer season. The variety Purple Top White Globe (39) produced large white roots averaging 235 grams in the soil bed. Overall, plants produced a high average freshweight of 8.93 kg/m2 (Photo 21). An attempt to grow turnips in the fall months failed as a result of low light levels and loss of plants to aphid infestation.

Although most northerners are familiar with turnip roots, the large fleshy leaves are also delicious as a cooked vegetable. Turnips are highly recommended for production in both indoor and outdoor gardens. The production of the winter swede turnip or rutabega should also be considered for summer production. This vegetable is frost hardy and like potatoes, may be stored for use during the winter months.

TOMATO

A number of tomato varieties were tested in the greenhouse throughout the year. In the summer, the mid-sized Sub Arctic Maxi (40), a determinate bush type, was tested in soil beds with the container variety Patio (40). The small fruited Toy Boy (42) was grown in hanging planters around the greenhouse.

Plants of Sub Arctic Maxi (41) grew very well, producing large quantities of flowers and a continuous supply of 40 to 60 mm diameter fruits over a period of 2 months in September and October. Total yields of this variety were 13.02 kg/m2 or an average of 1.3 kg/plant. These yields compare favorably with greenhouse averages of 12.8 kg/m2/crop published by Statistics Canada (1977).

Toy Boy plants (42) benefitted from increased direct sunlight and warmer air temperatures at the level of the hanging planters. Fruits of this variety were of exceptional quality averaging 505 grams/plant or 7.07 kg/m2 over a 3 month harvest season (September to November). Both of these varieties were exposed to a wide range of summer, fall and winter conditions and can be strongly recommended for year-round cultivation by future projects.

The variety Patio (49) received limited space and lighting in the summer months and as a result developed slowly. In September the plants were relocated to hanging planters where they quickly began flowering and fruiting. By the end of November, Plants had produced an average of 456 grams of tomatoes per Plant and were still in full production.

In addition to the above trials, 7 varieties of tomato were initiated from seed at the end of June and were subsequently transplanted into soil beds and boxes for growth during the winter months. All responded well to winter conditions in the greenhouse, particularly those grown closer to the light source in hanging planters.

Good growth was noted for the **medium-sized** varieties Burpee's Pixie Hybrid (which produced an average of 595 9/Plant by December 1), the small-fruited Toy Boy (404 9/Plant by Dec. 1), the full-sized Vendor VFT **(1660** g/plant) and the cherry variety Tiny Tim (228 g/plant by Dec. 1) (Photo 12).
The lack of adequate ventilation in the winterized greenhouse did result in some flower and fruit deformation and cracked skins.

The overall high performance and productivity of the tomato crops tested in 1986 is encouraging for future developments. Tomatoes are an important Part of the current vegetable market in northern **communities** and their production is highly recommended on a year-round basis.

4-2-4 SUMMARY OF HORTICULTURAL RESEARCH

A total of 65 varieties of 18 different vegetable **cultivars** were tested over 3 seasons in the Pond Inlet greenhouse and cold frame gardens. These may be divided into a number of groups according to their horticultural potential for use in future northern projects.

[1] Successful in Greenhouse

- Cucumber, tomato and lettuce varieties were successfully grown in greenhouse trials over all 3 seasons and are **recommended** as primary candidates for year-round cultivation.

Seasonal (summer, possibly spring) cultivation of bush beans, beets, chinese cabbage and turnips was also demonstrated to be **horticulturally** viable. Greenhouse cultivation of these conventional field crops resulted in increased yields 2.5 to 6 times over southern field estimates!

2] Limited Success **in** Greenhouse

- **Varieties of carrot, kale, kohlrabi, spinach, swiss chard** and zucchini demonstrated inadequate growth and productivity in the greenhouse and cannot be recommended as potential indoor **cultivars.**

- They should however, be considered for outdoor cultivation as previous studies have demonstrated considerable potential for production in cold frames **(Romer,** unpublished; **Bergsma,** 1986).

[3] Cold Frame Cultivation

- Only onion sets and radishes were completely successful in cold frames in **1986.** The remaining varieties suffered from **suboptimal** temperature and light conditions.

- All vegetable varieties tested in 1986 (except tomato, cucumber and green pepper) have been successfully produced under cold frame conditions in Rankin Inlet and Alexandra Fiord and should be considered for future projects.

RECOMMENDATIONS

(A) The horticultural feasibility of a number of important crops including cabbage, **caul** i flower, carrots and onions remains to be determined. These **cultivars** represent a substantial component of the current market and merit a thorough investigation , particularly in outdoor facilities.

(B) Market studies must be undertaken for newly-introduced varieties demonstrating horticultural **viability** under northern conditions. Vegetables including kale, kohlrabi , **chinese** cabbage, beet tops, zucchini, spinach and **swiss** chard may be grown seasonal **ly** in cold frames and gradually introduced to local markets for evaluation and trial by consumers.

(c) A **commercial viability** and cost benefit analysis should be done with **all** successful **cultivars** (section 5 examines 1986 trials) and comparisons made between indoor and outdoor Production.

4-3 EVALUATION OF GROWTH SYSTEMS

4-3-1 SOIL BEDS

[Al Soil Mixture

The local soil mixture developed for the growth trials was suitable as a medium for vegetable production. The mixture retained adequate moisture without becoming waterlogged. Soil beds with mature plants required a thorough soaking 3 to 4 times per week in summer and once or twice per week in the winter. Some algal growth was detected on the soil surface in the fall and winter due in part to inadequate air circulation.

TABLE 11 : Nutrient and PH analysis of local soil components and final mixture used in 1986 trials.
(Parts per mill ion in 2:1 water media extract)
(BDL = Below detectable levels of procedure)

	ORGANIC PEAT	FINE SAND	1:1 MIXTURE	SUFF. RANGE
PH Level	5.8	7.7	6.0	5.5-6.9
NITROGEN				
Ammonium	0.8	0.1	0.6	0 - 20
Nitrate	96	1	49	35 - 180
Nitrite	BDL	BDL	BDL	---
PHOSPHOROUS	0	0	0	5 - 50
POTASSIUM	10	6	7	35 - 300
SODIUM	40	6	25	0 – 30
CALCIUM	115	18	56	60 - 400
MAGNESIUM	59	BDL	26	30 - 200

Analysis conducted by Soils and Animal Nutrition Laboratory, Alberta Department of Agriculture
Edmonton, Alberta

The nutrient content of the local soil mixture was inadequate to support growth without the addition of fertilizers. This is supported by the results of a nutrient analysis presented in Table 11.

Levels of Nitrogen are low, particularly as Ammonium (0.6 ppm) and Nitrite ions (below detectable levels). Some Nitrate was detected in the peat and this may eventually be broken down by bacterial action and contribute to plant nutrition. Levels of the two other essential macronutrients Potassium (7 ppm) and Phosphorous (O ppm) were also very low and well below sufficient levels.

Nutrient levels were considerably higher in the peat than in the sand component of the mixture. The pH of the mixture (an acceptable 6.0) was a balance between the mildly acidic organic peat (5.8) and the alkaline sand substrate (7.7).

The regular addition of chemical fertilizers at various strengths depending on the plant variety and stage of development provided the vegetables with an adequate supply of missing nutrients.

[B] **Outdoor Gardens**

The outdoor growth facilities developed in Pond Inlet cannot be fairly assessed due to the uncharacteristically poor growing season experienced in 1986. The design of the cold frames used, however, was successfully tested over a five-year period in Rankin Inlet and proved very effective for the summer production of vegetables on a small scale (Romer, unpublished).

The cold frames are sturdy and effectively resist winds to provide protection for plants. The frames are easily covered with plastic in the spring to permit rapid set-up. The cover shelters the tender seedlings from damaging rain and wind and retains warmth to enhance the plant's microclimate.

The igloo tents described in Section 2 were not set up in 1986 due to a lack of available soil resources in the spring. The igloo design for northern greenhouses is effective as it optimizes solar input to the growing areas at all times of day. For more information concerning the design and microclimate of these structures, refer to Bergsma (1986).

The 45 gallon drums provide easily available, no-cost containers when cut in half, fOr growing cool-weather crops outdoors. They have been successfully used in previous northern trials both as plant containers (Romer, 1983) and as heat storage mass (Webb, 1977).

4-3-2 NFT HYDROPONIC BED

The NFT hydroponic bed designed for the Pond Inlet greenhouse was modified many times in the course of the 1986 trial season. The bed, as described in Section 2, is the final product of these alterations and its success is reflected in the performance and productivity of tested lettuce crops.

The system of seed initiation using Jiffy 9 peat pellets proved very successful and could be efficiently used on a large or small scale. The pellets were easily inserted and removed from the gutters to permit rapid changeover of crops and cleaning of the system. The entire NFT system was, in fact, easily disassembled for easy repairs, replacement of parts and cleaning.

The black plastic covers performed a dual function in the operation of the NFT system. Their primary function was to prevent light from reaching the roots and nutrient solution. On sunny days, however, the plastic absorbed solar radiation thus warming the nutrient solution and enhancing conditions at the root zone.

There were a number of limitations identified with the system during the course of the year :

[1) The small size of the gutters and lack of vertical supports restricted use of the system to small self-supporting vegetables. Cultivation of tomatoes and cucumbers would require larger channels for their greater root mass and some system of stakes or nets to support the plants for efficient vertical growth.

[2] The fixed spacing between gutters (rows) became insufficient for some varieties tested as they reached maturity. This problem could be alleviated in future designs by incorporating a system of adjustable gutters where spacing could be increased as plants grow.

[3) The use of rounded gutters resulted in progressive damning of nutrient solution as plant root mats developed and blocked flow. This may be rectified by using flat gutters which have greater space for nutrient flow.

The NFT hydroponic bed designed for use in Pond Inlet was most effective as a system for lettuce production.
This form of hydroponic culture may have important economic benefits in terms of reducing labour and energy costs. This is discussed in Section 4-3-4.

4-3-3 GRAVEL HYDROPONIC BED

In contrast to the NFT water culture bed, the gravel culture demonstrated only limited success in 1986. Plants grown in the beds performed very poorly, developing very few roots and accumulating little biomass over long periods of time. The problem was mainly attributed to a faulty design in the water delivery system. Most conventional gravel culture systems utilize a sub-irrigation system. Water floods the growing beds to within several inches of the surface, then drains back to the reservoir. This type Of system, however, requires a considerable cost investment in terms of timers and valves (in addition to the pump).

A less expensive system was designed in 1985 for Pond Inlet using a trickle feed delivery. in this design, water from the reservoir is continuously fed to the plants by the trickling of nutrient from a perforated ‘ooze” tube. A number of problems were soon diagnosed.

1. The pump chosen for the system could not apply sufficient pressure to the hose to permit equal distribution of water along its entire length.
2. The medium used (Haydite) had a tendency to fracture and produce a fine silt which circulated through the system and resulted in the gradual plugging of delivery holes in the hose.

Despite attempts to modify the system, the performance of plants did not improve. The conversion from trickle feed to sub-irrigation would not have been practical so the beds were converted to NFT hydroponics in the winter.

Other disadvantages associated with the use of gravel substrate include:

- difficulties in sterilizing and cleaning of the medium after crop harvest and before replanting
- accumulation of salts in the medium
- difficulties in controlling algal growth caused by high humidity and nutrient levels.

Additional trials in gravel or sand culture hydroponics would be required to adequately assess its potential as a production system for the north. Future studies ahould include an investigation of local substrates (sand, gravel, peat) since importation of commercial materials **such as Haydite is expensive and Uneconomical.**

4-3-4 COMPARISON OF SOILLESS HYDROPONIC CULTURE WITH CONVENTIONAL SOIL CULTURE

[A) Start-up Costs

The use of soil is cost effective and labour intensive when local resources are available. A cubic meter of soil can be processed in one man-day and provides an effective growing area of 3 m2. The materials required for the growing bed may be found locally or purchased (equivalent to 2 sheets of plywood) .

SOIL :	soil delivery	10.00	(1/4 load)
	processing	80.00	(man-day)
	frame	100.00	(materials & assembly)
	TOTAL COST	$190.00	

The start-up cost of an equivalent area of NFT hydroponics similar to that designed for Pond Inlet is almost double and may be summarized as follows:

NFT HYDROPONICS :	frame (as above)	100.00
	gutters	100.00
	pump	50.00
	plastic, filters tubing etc.	20.00
	labour (day)	80.00
	TOTAL COST	$ 350.00

In addition, the assembly of hydroponic systems generally requires more skilled labour than for soil systems which further contributes to an increased start-up cost.

[B] Operating Benefits

Although initial capital costs are more expensive, hydroponic systems offer a number of advantages over soil based systems.

(1) Maintenance of System

The NFT hydroponic system is easily cleaned and sterilized between crops. Gutters and reservoir may be disassembled and cleaned with bleach or Hydrochloric Acid to eliminate undesirable pathogens.

Soil culture sterilization is a costly and lengthy labour-intensive procedure often taking weeks and involving the use of steam and/or chemical fumigants.

(2) Pest Control

Hydroponic culture reduces the occurrence of soil-borne pathogens and pests which would require costly chemicals and careful crop rotation techniques to control. Some forms of pathogens may, however, be spread more rapidly in hydroponic culture and be more difficult to isolate. A water-borne infection may circulate through the entire system in less than an hour to contaminate the entire crop.

(3) Plant Nutrition

Hydroponic systems may be fully automated and as a result, solution nutrient and acidity (PH) levels may be controlled more precisely to provide optimum growing conditions for plants. The continuous circulation of nutrients ensures that all plants receive equal and adequate amounts.

In contrast, plant nutrition in soil systems is highly variable. Concentrations of nutrients vary between areas and localized deficiencies are often present but cannot be easily detected. Much of the fertilizer applied to soil beds drains out of the system and is not available to plants.

(4) Water Conservation

Water conservation is an Important consideration in the Arctic, particularly in communities where existing resources are already limited. Soil systems require 2 to 3 times the volume of water as a similar area of hydroponic bed. Much of the water applied to soil beds is lost to percolation and evaporation and plants may be subjected to periods of water stress which affects productivity.

Water culture eliminates water stress and may be fully automated to reduce labour costs. A Power failure, or imbalance in the nutrient levels may, however, result in the loss of the entire crop, a disaster unlikely to occur in soil systems.

(5) Energy Conservation and Productivity

Water culture may contribute significantly to energy conservation and increased production of vegetables in greenhouses. Studies have shown that nighttime air temperatures may be reduced by UP to 10 C without significant decreases in yield provided the nutrient solution is heated.

Two hydroponic studies in Southern Ontario have demonstrated that a 40-50X savings in energy costs may be realized by reducing nighttime temperatures in NF greenhouses (Mueller, 1982; Inmarint, 1984). In addition, yields of crops grown at 5 C (night air T C) were 15% greater in heated versus unheated systems (Cooper, 1979) .

The nutrient solution may be heated passively by means of a solar collector or by the circulation of waste heat through coils in the reservoir. Supplementary heat may be provided by an immersion heater.

(6) Processing

Hydroponic culture produces a cleaner crop, free of sand and dirt, which makes it more attractive and easier to prepare by the consumer.

(7) Productivity

Studies have demonstrated that yields of hydroponically-grown produce are significantly higher than those of soil-cultured produce. Greenhouse tomatoes grown in hydroponic culture averaged 8-9 kg/year/Plant or 20-150 % greater than soil-grown crops which averaged 3.6 - 6.8 kg/year/plant (Resh, 1985). The use of NFT over peat bag hydroponic culture further increased yields by 26 %.

In Pond Inlet, the productivity of lettuce, kale and chinese cabbage was compared between NFT hydroponic and soil culture beds. The results are presented in Table 12.

TABLE 12: Comparison of freshweight yields of vegetables grown in soil versus hydroponic culture.

VARIETY	CULTURE	YIELD (kg/m2/month)	PERCENT DIFF.
Chinese cabbage	soil	7.87	
Jade Pagoda	NFT	8.00	- 2%
Kale	soil	3.38	
Tall Scotch Curled	NFT	2.99	- 13%
Lettuce	soil	6.16	
Grand Rapids	NFT	9.60	+ 56%
Lettuce	soil	1.27	
Ruby Red	NFT	3.37	+ 165%
Lettuce	soil	8.03	
Simpson	NFT	10.00	+ 25%

The difference in productivity between soil and hydroponic culture was most clearly demonstrated with lettuce crops tested in 1986. Yields in the NFT bed were 25 and 65 % greater than in adjacent soil beds. In contrast. yields of kale were 13 % greater in soil versus hydroponic beds. No significant difference was obtained between chinese cabbage grown in soil or hydroponic beds.

The arguments and data presented in this section tend to favour the use of hydroponic systems in northern greenhouses. The limited size of this study permitted the effective examination of only two kinds of vegetables (lettuce and chinese cabbage) and one hydroponic system. Future projects should investigate the performance of other popular vegetables, particularly tomatoes, cucumbers and peppers, and different techniques of hydroponic culture.

The use of soil cultivation should not be totally disregarded as it represents an integral part of summer outdoor cultivation (see Section 7-4-2).

SECTION 5: ECONOMIC ANALYSIS

This section presents a cost/ benefit analysis of the Pond Inlet greenhouse project and examines the economics of northern vegetable production. Section 5-t includes a brief discussion of capital costs followed by an analysis of the annual and seasonal operation costs in Section 5-2. in Section 5-3, unit costs of locally-produced vegetables are compared with imported produce.

5-1 CAPITAL COSTS

The exact figures for start-up expenditures of the Pond Inlet project are not available for this report. In his 1985 report. Peter Poole estimated that the greenhouse as installed in July 1985 (Phase 1) could be made up as a ready-to-assembl e kit for a maximum of $10,000.

The capital investment for a northern greenhouse may be largely determined by the length of the expected operating period and the sophistication of the systems used. In the greenhouse feasibil ity study conducted in Hay River (Ferguson, 1982) it was estimated that investment levels for a 10,000 ft2 greenhouse would increase 200 % from $140,000 for a 9-month operating period to $290,000 for a year-round facility, due primarily to the high cost of installing artificial lighting and insulating systems.

The study estimated that a seasonally-operated (7 months) 10,000 ft2 (930 m2) greenhouse would require a capital investment of $135,000 or $13.50/ ft2 ($145.00/m2). This value could even double if lighting and winterization systems are included.

5-2 OPERATING COSTS

The operating costs may be broken down into four categories: a) electrical, b) heating, c) materials and water and d) labour. The estimates and values discussed will only consider operating costs with respect to a commercial project. The cost of research equipment and initial capital investment will not be included in this analysis.

In the following sections, the methods used to calculate costs are given for :

(a) 1986 actual cost
(b) expected costs for future seasons
(with systems fully operational)

The actual operating costs calculated for 1986 are presented in Table 13. The estimated annual operating costs for future years are shown in Table 14.

5-2-1 ELECTRICAL COSTS

In 1986, power was required for the operation of 3 fans, 2 lighting systems and 2 hydroponic pumps. The monthly cost of power for each of these utilities is calculated according to the following equation:

COST = Operating x Power x $0.29 / KWhr
$/month hrs/month rating KW

[A] SOLAR COLLECTOR FAN (0.3 KW)

1986

June-Aug : Fan hours were estimated on the basis of Bright Sunshine Hours (Fig 8) between 0900 and 1700 hrs.
June - 45 minutes/ hr Bright Sunshine
July and Aug. - 30 rein/ hr Bright Sunshine
Sept–Dec : Actual operating hours were recorded using Cramer elapsed time hourmeters.

Annual

The effective operating period of the collector extends from March to September between 0800 and 1800 hrs when the sun is in the southern hemisphere. The fan is expected to operate an average of 30 minutes per hour of Bright Sunshine. (This may be thermostatically controlled.) There is no accurate means of estimating the % of Bright Sunshine Hours between 0800 and 1800 hrs but for the purposes of this report, the fan hours will be estimated at:

COLLECTOR FAN hours/ month = 50% of Bright Sunshine Hours
(monthly means 1983-85 averaged)
(Table 2)

[B] EXHAUST FAN (0.138 KW)

1986

The exhaust fan was installed in August and only operated for a total of 6 weeks. Fan hours were recorded by the hourmeter.

Annual

The effective operating period for the exhaust fan extends from April to September when there is no insulation in the greenhouse. The fan operates principally to cool the greenhouse on sunny days. The operating hours are estimated for this report to be:

EXHAUST FAN hours/month = 25% of Bright Sunshine Hours (monthly means 1983-85 averaged) (Table 2)

[C] HEATER FAN (0.2 KW)

1986

June-Aug :	Fan was switched off in June and July (except for a cold spell July 23-27). In August, hours were estimated based on the number on events (ON-OFF) per evening recorded by the thermograph chart.
Sept-Dec :	Fan hours were recorded by hourmeter.

Annual

The estimation of annual operating hours for the heater fan was calculated using Table 6 : Annual Energy Balance.

Heating requirement = Greenhouse heat loss - Solar heat contribution + Equipment heat cont.
[KJ heat/month] Table 6, [D] = [KJ/month] [A] - [KJ/month] (B) + [KJ/month] [C]

The heat generated by the glycol heater per hour of operation was estimated using the flow rate through the heater and the temperature difference between incoming and outgoing supply lines (courtesy of Lloyd Bast, NCPC Power Engineer).

Heat Generated **(KJ/hr)** by **Glycol** Unit Heater :

(1) Flow rate = 2.172 ft3 **/** min.

(2) Temperature difference **(ΔT°C) between incoming and outgoing glycol lines (with fan ON) :**

(a) May - **Oct** = **1.6°C**
(b) Nov - Apr = **1.9°C** (*)

(*) In the winter months, the **glycol** temperature is raised to meet the increased heating requirements of the hotel .

(3) Specific density of **glycol** = 1.0544

(4) Water generates 118.43 **KJ/°C/ft3** SD = 1.0

(5) Heat released by one cubic foot of **glycol** for every **1** C drop in temperature recorded :

(3) x (4) **= 124.87 KJ/°C/ft3**

(6)

HEAT GENERATED by heater **(KJ/hr)**	**=**	**124.87 KJ/°C/ft3** (5)	x	**Δ T°C** (2)	X	FLOW RATE ft3/min **(1)**	X	60 rein/ hour

(7) HEAT GENERATED : **May-Oct** = 26,034 **KJ/hr** of operation
BY HEATER **Nov-Apr** = 30,918 **KJ/hr** of operation

(8) Fan hours were then calculated as follows:

HEATER FAN operation **hrs/month**	=	Heating requirement KJ heat/month (Table 6) [D]	-:-	Heat generated **KJ/hr** (7) (depending on month)

In **addition to these three fans, the future** addition of a circulating fan and 1 to 3 heat exchange fans may be considered. These fans are **very** low power drains and should add only marginally to the overall production costs.

[D] METAL HALIDE LAMP

Bulb - (1.0 KW)
Ballast - (0.552 KW)
TOTAL - (1.552 KW)

1986

The operation of the lamps was controlled by program timers. The following timetable was in effect :

May 16 - May 20	24 hrs/day	
May 21 - Jun 7	18 hrs/day	
Jun 8 - Aug 20	OFF	
Aug 21 - Oct 14	7 hrs/day	(1600 - 2300 hrs)
Oct 15 - onwards	16 hrs/day	(0700 - 2300 hrs)

Annual

The metal halide lamp will be expected to provide supplementary lighting in the fall and complete lighting in the winter season according to the following timetable :

Apr - July	OFF	
Aug - Sept	7 hrs/day	(1600 - 2300 hrs)
Oct - March	16 hrs/day	(0700 - 2300 hrs)

[E] FLUORESCENT LIGHTS

Bulbs	8 X 40W	= (0.32 KW)
Ballasts	4 X 96W	= (0.384 KW)
TOTAL		= (0.704 KW)

1986

The seedling racks were completed and operational as of August 1st. The hours of operation from August to December were between 0700 and 2300 hrs or 16 hrs/day.

Annual

Apr - July	OFF	
Aug - March	16 hrs/day	(0700 - 2300 hrs)

[F] HYDROPONIC PUMPS

57.5 KW/ pump x 2 = (0.115 KW)

1986

Jun 14 - Aug 14	24 hrs/day - 1 pump (NFT)
Aug 15 - Oct 31	24 hrs/day - 2 pumps
Nov - Dec	24 hrs/day - 1 pump

Annual

It is estimated that both pumps will run continuously 24 hrs/day year-round.

5-2-2 HEATING COSTS

The calculation of heating costs was based on the heating requirements of the greenhouse (KJ/ month) calculated in Table 6, Part [D) : Net Glycol Heater Contribution.
In order to place a dollar value on the heat contributed by the hotel, the determination of an "oil equivalent cost" was made :

OIL EQUIVALENT = Quantity of oil required to generate an equivalent amount of heat.

(1) One gallon of fuel oil #2 grade generates 147,609 KJ of heat and is generally burned at 60 % efficiency, therefore :

147,609 x 60 % = 88,565 KJ / gallon

(2) The current value of the oil is $0.46 / gallon.

(3) HEATING COST (oil equivalent) $$

$$\text{HEATING COST (oil equivalent) \$\$} = \frac{\text{Heat requirements KJ/month (Table 6)}}{\text{88,565 KJ/gallon}} \times \text{\$ 0.46 /gallon}$$

For 1986, the actual hours of operation were used to determine heat produced by the heater. These values were then used to determine the oil equivalent cost.

5-2-3 MATERIAL AND WATER COSTS

The cost of materials is a combination of production and replacement costs and is estimated as follows:

(A) Annual Production Costs

Soil Culture	$/m2/crop	# crops	$/m2/yr
seeds	0.50	6	3.00
Jiffy pellets and seed soil	1.00	6	6.00
Fertilizer	0.10	26(*)	2.60

TOTAL COST SOIL =
$11.60/m2/yr
$ 0.97/m2/mo

NFT Hydroponics			
seeds	0.10	6	0.60
Jiffy 9 pellets	1.50	6	9.00
Fertilizer	0.20	26(*)	5.20

TOTAL COST HYDROPONIC =
$14.80/m2/yr
$ 1.23/m2/mo

(*) frequency of change or application.

GREENHOUSE COSTS :

[a] = **$11.60/m2/yr** x 7.4 **meters2** of soil beds = **$85.84**

[b] = **$14.80/m2/yr** x 6.0 **meters2** hydroponic beds = $88.80

TOTAL COST MATERIALS (PRODUCTION) (A) = [a] + [b] = $\frac{\$174.64/yr}{12}$ = $14.55/month

(B) Annual Replacement Costs

These figures will only include the cost of lighting as no estimates for lifetime of fans **could** be found. the lifetime of lights was estimated from projected hours of annual operation (see Section 5-2-l). The cost/ month of the **lighting** was averaged over the 7 months that the light systems were operating. Since **lighting** systems were only used for 7 hrs / day during August and September, the cost was combined and charged only to September.

	Actual cost	Lifespan (years)	Annual cost	$/month Operation
Metal Halide	$100.00	2	$50.00	$7.14
Neons (8)	$160.00	1.3	$120.00	$?7.14

TOTAL REPLACEMENT COSTS (September - March) = $24.28 / month

·**TOTAL** COST OF MATERIALS :

April – August (Lighting OFF) = Production Costs (A) = $14.55/m

Sept - **March (Lighting ON)** = **Production Costs (A)** + **Replacement Costs (B)** = **$38.83/m**

WATER COSTS

The costs for delivery of water and removal of sewage are combined in Pond Inlet and are currently $0.05/gallon. Since the greenhouse does not require waste removal, the rates will be calculated at 50X of the rate or $0.025/gallon.

Based on observations made in 1986, water consumption values were estimated. Water utilization during summer months was substantially higher than during winter months due to increased rates of transpiration and evaporation.

Summer Consumption = (April-Sept)	Hydroponic Beds	140 gallons/month
	Soil Beds	240 gallons/month
	TOTAL = 380 gal x $0.025 = $9.50/m	

Winter Consumption = (Oct-March)	Hydroponic Beds	80 gallons/month
	Soil Beds	120 gallons/month
	TOTAL = 200 gal x $0.025 = $5.00/m	

5-2-4 LABOUR COSTS

The calculation of labor costs poses a number of difficulties which must be considered carefully in order that an accurate estimate may be provided.

Actual versus Adjusted Salaries

The actual salary paid out in 1986 to the horticultural trainee working in the Pond Inlet greenhouse does not reflect the potential growing area which **could be effectively maintained by that employee. The greenhouse contains a total growing area of only 13.4 m2. The actual labour costs in 1986 (excluding manager's salary) were:**

$$\text{ACTUAL SALARY} = \frac{\$12,000.00\ /\ \text{year}}{13.4\ \text{m}2} = \$895.44\ /\text{m}2\ /\text{yr}$$

$$= \$66.82\ /\text{m}2\ /\text{mo}$$

This value by itself would render the commercial production of vegetables unfeasible in any season. It is necessary, therefore, to adjust the salary values to more accurately reflect the cost of labour in a commercially-sized greenhouse.

For the Purposes of this report, we will use labour costs estimated for a 1,000 m2 greenhouse in Hay River (Ferguson 1982) as a basis for determining the adjusted salary values in Tables 13 and 14.

$$\text{Hay River 1982} \quad \frac{\text{Labour Costs}}{\text{Area}} = \frac{\$36,000}{1,000 \text{ m2}} = \$\ 36.00 \text{ /m2 /yr}$$

This value will be adjusted fOr inflation and increased cost of living to a value of $50.00/m2/yr.

$$\text{ADJUSTED LABOUR COSTS POND INLET} = \frac{\$50.00/\text{m2} \times 13.4 \text{ m2}}{12 \text{ months}} = \$55.83/\text{mo}$$

$$= \$4.16/\text{m2/mo}$$

5-2-5 COLD FRAME GARDENS

For the purposes of this report, the monthly operating cost for cold frame gardens will be assumed to be the same as for the greenhouse during the summer season ($9.29/m2/m). Although no electrical costs are incurred for the cultivation of outdoor crops, there are additional labour costs associated with the set-up and preparation of cold frames.

5-2-6 SUMMARY OF OPERATING COSTS

The operational cost summaries are presented in Tables 13 and 14. The latter table is a better reflection of costs in a fully operational greenhouse and will therefore be used for this discussion. The costs presented will be compared to figures estimated for a 10,000 square foot greenhouse in Hay River (Ferguson 1982).

[1] ANNUAL TOTALS

The annual operating cost of the Pond Inlet greenhouse based on a 12 month period is estimated to be $3990.00 or $298.00 per square meter of growing space. This compares with a value of $110.00 /m2 estimated for the Hay River greenhouse.

Electrical demand represents the largest component (69%) of annual costs and of these, lighting systems are the costliest element. The operational costs of Metal Halide and fluorescent lighting systems is estimated at $2300.00 per annum (August -March) or 58% of annual operating costs! This value ($170.00/m2/yr) is 8 times greater in comparison to the Hay River greenhouse estimate of $20.45 /m2 /yr.

TABLE 13 : Operating costs of the Pond Inlet greenhouse from May to November, 1986

	MAY (15-30)	JUN	JUL	AUG	SEP	OCT	NOV	TOTAL
ELECTRICAL								
COLLECTOR FAN		4.44	2*96	1.45	3.60	0.70	-	13.23
EXHAUST FAN				0.26	0.75	-		1.01
HEATER FAN			0.29	2.29	11.02	12.70	1.21	27.51
METAL HALIDE LAMP	143.12	56.72	-	34.66	94.51	166.52	216.05	711.58
FLUORESCENT LAMPS				101.27	97.99	101.27	97.99	398.52
HYDROPONIC PUMPS		6.41	12.41	19.20	24.01	24.82	12.01	98.86
TOTAL ELECTRICAL COSTS :	143.12	67.57	15.66	159.13	231.88	306.09	327.26	1250.71
HEATING COSTS (Oil Equivalent)			0.65	5.34	25.72	29.59	3.34	64.64
MATERIALS	14.55	14.55	14.55	14.55	38.03	38.83	38.83	174.69
WATER	9.50	9.50	9.50	9.50	9.50	5.00	5.00	57.50
TOTAL MATERIAL AND WATER COSTS :	24.05	24.05	24.05	24. 05	48.33	48.33	48.33	232.19
LABOUR COSTS (Adjusted)	27.92	55.83	55.83	65.83	55.83	55.83	55.83	362.90
TOTAL OPERATIONAL COSTS / month	196.06	147.45	%.19	244.35	361.76	435.34	430.26	1910.44
($/m2/month)	14.56	11.00	7.18	18.24	27.00	32.49	32.11	142.57

TABLE 14 : Estimated annual operational costs for the Pond Inlet greenhouse in future seasons.

	JAN	FEB	HAR	APR	MAY	JUN	JUL	AUO	SEP	OCT	Nov	M C	TOTAL
ELECTRICAL													
COLLECTOR FAN			6.S0	13.40	17.43	14.7s	17.98	9.77	3.06				83.78
EXHAUST FAN				3.07	4.00	3,39	4.15	2.23	0.90				17.74
HEATER FAN	8.52	6.37	5.s7	14.34	4.62				7.76	0.88	3.S6	6.40	54.11
METAL HALIDE LAMP	223.24	201.64	223.24					97.67	94.61	223.24	216.05	223.24	1,502.83
FLUORESCENT LAMPS	101.27	91.47	101.27					101.27	97.99	101.27	97.99	101.27	793.80
HYDROPONIC PUMPS	24.82	22.42	24.82	24.01	24.82	24.01	24.82	24.82	24.01	24.82	24.01	24.82	292.20
TOTAL ELECTRICAL COSTS :	354.85	321.90	361.48	54.82	50.87	42.1S	46.9S	236.76	229.02	350.21	341.71	364.73	2,?44.4S
NG CO (Oil Equivalent)	15.29	17.63	15.42	39.71	10.76				18.08	2.04	10.13	14.95	144.01
MATERIALS	38.s3	38.83	38.83	14.s5	14.55	14.55	14.55	14.66	38.83	38.83	38.83	38.83	344.66
WATER	6.00	5.00	6.00	9.50	9.60	9.s0	9.60	9.60	9.s0	5.00	5.00	5.00	87.00
TOTAL MATERIAL ANO WATER COSTS :	43.83	43.83	43.83	24.06	24.06	24.05	24.06	24.0S	40.33	43.83	43.03	43.83	431.56
LABOUR COSTS (Adjusted)	66.S3	66.83	56.03	S6.83	55.83	56.83	65.83	S6.83	55.83	55.83	66.83	55.83	669.96
TOTAL OPERATIONAL COSTS / month	469.80	439.19	476.66	174.41	141.51	122.04	126.83	316.64	351.26	451.91	451.50	4s9.34	3,990.00
($/m2/month)	35.06	32.78	36.SS	13.02	10.56	9.11	9.46	23.66	26.21	33.72	33.69	35.03	297.76

This is a result of several factors :

1. Higher cost of electrical power
   ($0.29 vs $0.13 /KWhr)
2. Longer period of required utilization
   (Shorter daylength with increased latitude)
   (350 KWhr /m2 versus 154 KWhr /m2)

Labour costs (adjusted see section 5-2-4) are the second largest component, totalling $50.00/m2 or 17% of annual costs. This value may be reduced in a fully automated hydroponic greenhouse. The evaluation of costs for future projects must consider the salary and relocation costs of an experienced horticulturalist.

Heating costs are the smallest component (4%) of the annual operating budget averaging only $10.70 /m2. It is clear from these estimates that heating a greenhouse is substantially less expensive than lighting it. It would be economically beneficial therefore to maximize the utilization of available sunslight (regardless of heating cost) and limit indoor lighting to the dark periods alone (October to February) .

Annual costs for materials and water totalled $432.00 or $32.00 /m2 and represented 11% of the operating total. Replacement costs for lighting systems account for approximately half of the material costs.

[B] ANNUAL VERSUS 1986 COSTS

The total operating costs calculated between May 15 and November 31, 1986 compare favorably with the annual estimates (Tables 13,14). The breakdown of costs is similar:

Electrical	(55%)	Heating	(3.3%)
Materials	(12%)	Labour (Adjusted)	(19%)

Actual monthly operating totals for 1986 are within 5% of estimates for future seasons. If actual salaries were used in the place of adjusted figures, the 6 month operating total would increase by over 400X from $1910.00 to $8050.00! . Salaries would then rePresent 80% of the total operating costs and render the Project unprofitable.

The future use of the Pond Inlet greenhouse and recommendations for circumventing the problems of small growing space versus high salary are discussed in Section 7-6.

[C) SEASONAL TOTALS

The operating costs presented in Table 14 may be divided into four principle production periods (Table 15) in order to provide a clearer picture of seasonal expenditures. The seasons are determined according to the use of lighting, heating and insulating systems in the greenhouse and have been previously presented in Table 10.

As expected, the cost of greenhouse operation is lowest during the spring and summer seasons when costly lighting systems are not required (Table 15). Costs are estimated at $11.79/m2/month in spring and $9.29/m2/month in summer seasons or 7.9% and 6.3% respectively of total annual operating expenditures.

During the fall, requirements for supplementary lighting increase operating costs to $24.89/m2/month and this season represents 16.7% of the annual expenditures.

The winter season extends over 6 calendar months and is the costliest of all, both on an annual as well as a monthly basis. Costs are estimated to be $34.30/m2/month at this time or 270X higher than during the summer season. Although the winter season occupies half the year, the total seasonal operating cost of $2758.00 is 69% of the annual operating costs.

The large differences in monthly costs between seasons can be directly correlated to the increased electrical demand imposed by lighting systems. In the fall and winter seasons, electrical costs represent 70% and 76% of total monthly expenses. This compares with only 36% and 33% for spring and summer months respectively.

When assessing the overall viability of northern greenhouse production, it may be of value to provide comparative income and expenditure statements for different lengths **of operation. In Pond Inlet, the high operating cost of the winter season will be the most significant factor** in determining economic viability of a year-round facility. The estimated costs of operating the greenhouse over 3 seasons (Spring, Sumner, Fall) are $1232.00 or $92.00 **/month. This value triples to** $3990.00 if operation is extended to include the winter season.

TABLE 15 : Estimated seasonal operational costs ($/month) for the Pond Inlet greenhouse in future years.

	SPRING (Apr-May)	SUMMER (Jun-Jul)	FALL (Aug-Sep)	WINTER (Oct-Nov)
Season Length (months)	**2**	**2**	**2**	**6**
Electrical	**52.85**	**44.55**	**232.39**	**347.48**
Heating	**25.23**	**- - -**	**9.04**	**12.58**
Materials	**24.14**	**24.14**	**36.20**	**43.77**
Labour (*)	**55.83**	**55.83**	**55.83**	**55.83**
MONTHLY TOTALS				
$ / month	158.05	124.52	333.46	459.66
$ /m2 /month	11.79	9.29	24.89	34.30
TOTAL SEASONAL COST	316.10	249.04	666.92	2757.96
PERCENT OF ANNUAL COST	7.9 %	6.3X	16.7 %	69.1 %

6 MONTH OPERATIONAL COST : (April - September)	$ 1232.04 / greenhouse $ 91.94 / m2 $ 15.32 / m2 / month
ANNUAL OPERATIONAL COST : (12 Months)	$ 3990.00 / greenhouse $ 297.00 / m2 $ 24.81 / m2 / month

(if) adjusted labour rate
(Section 5-2-4)

Section 5-3 Value of Imported Produce

Before considering the values of local produce grown in the Pond Inlet greenhouse, it is first necessary to determine the current value of imported produce and the factors which influence import and retail prices. The actual current purchase price to the consumer will establish the threshold against which the viability of local production will be measured.

The current levels of local vegetable production in Pond Inlet are presented in Table 16. These estimates have been obtained from the Toonoonik-Sahoonik Co-operative which markets an estimated 50X of the town's produce and is responsible for air freight handling of goods coming into the community (after Poole 1985, revised 1987).

An estimated 10,412 kilograms of produce is consumed annually in Pond Inlet. Of the 9 primary imports, cabbage, carrots, onions and potatoes are the most important representing 70% by weight of all imports. The wholesale cost of these vegetables in Ottawa is $9,431.00, but this value increases 340% to a landed cost in Pond Inlet of $41,604.00 (Total Import Cost).

The value calculated for Total Import Cost is based on a government subsidized freight rate of $3.09 /kg. In actual fact, two subsidy rates are available to northern communities :

1. Mail Freight Subsidy ($2.09 /kg to Pond Inlet) is applied to produce dispatched through the Val D'Or and Kapuskasing post offices only.
2. Perishable Freight Subsidy ($3.09 /kg) for produce originating from all southern centers.
3. Regular Freight Rate (non-subsidized) of $6.09 /kg applies to all regular freight entering the community.

Table 17 provides an indication of the effect of freight subsidies on the local import costs and final retail value of the produce in Pond Inlet. It is apparent from this table that freight subsidies play an important role in the vegetable economy of northern communities.

TABLE 16 **: Estimates of annual purchase of vegetables in Pond Inlet (Poole 1985; revised)**

VEGETABLE	TOTAL KGS	WHOLE-SALE COST	FREIGHT COST ($3.09/kg)	TOTAL IMPORT COST	% OF TOTAL IMPORTS
CABBAGE	**1192**	**1217.00**	**3683.00**	**4900.00**	**12.0**
CARROT	**1192**	**657.00**	**3683.00**	**4340.00**	**11.0**
CAULIFLOWER	**182**	**315.00**	**562.00**	**877.00**	**2.0**
CUCUMBER	**560**	**414.00**	**1730.00**	**2144.00**	**5.0**
LETTUCE	**954**	**1431.00**	**2948.00**	**4379.00***	**11.0**
ONION	**2364**	**1560.00**	**7305.00**	**8865.00**	**21.0**
GREEN PEPPER	**186**	**262.00**	**575.00**	**837.00**	**2.0**
POTATO	**2546**	**1400.00**	**7867.00**	**9267.00**	**22.0**
TOMATOES	**1236**	**2175.00**	**3820.00**	**5995.00**	**14.0**
TOTALS	10,412	9,431.00	32, 173.00	41,604.00	

TABLE 17 : Effect of freight subsidies on local costs of vegetables in **Pond Inlet.**

FREIGHT RATE	WHOLE-SALE COST *	TOTAL FREIGHT COST	TOTAL **IMPORT** COST	**25%** MARKUP	TOTAL RETAIL COST
$2.09	**9,431**	**21,761**	**31,192**	**7,798**	**38,990**
$3.09	**9,431**	**32,173**	**41 ,604**	**10,401**	**52,005**
$6.09	**9,431**	**63,409**	**72,840**	**18,210**	**91,050**

(* from Table 16)

As **mentioned earlier, the present import cost of produce in Pond Inlet is $41,604. The actual import cost of this produce** without subsidies would be $72,840. The Total Freight Subsidy therefore applied to Pond Inlet is $31,236.00 per year or 43% of **actual import costs. This value represents 8 times the annual operating costs of the Pond inlet Gardens!!**

The <u>Retail Value</u> of vegetables currently consumed in the community is $52,000.00 but would rise to a value of $91,050.00 if subsidies were eliminated.

Realistically, the current retail prices in Pond Inlet must be used to determine the threshold of viability for local production. However, for the purposes of comparison, the local production costs of vegetables will be assessed against both subsidized and unsubsidized import costs.

Section 5-4 Value of Local Greenhouse Produce

The unit cost ($/kg) of vegetables produced in the greenhouse during 1986 is presented in Table 18. To generate this table, yields of selected successful greenhouse varieties (Section 4) were used to obtain mean monthly production values (kg/m2/month). These figures may be considered baseline levels of production which may be expected to increase in future years under improved climatic conditions.

$$\underset{(\$/\text{kg})}{\text{UNIT LOCAL COST}} = \frac{\text{Operating costs}}{\text{Plant Yield}} = \frac{\$/\text{m2}/\text{month}}{\text{kg}/\text{m2}/\text{month}}$$

The unit price for vegetables varies significantly between seasons as a function of operating costs. Costs are highest in winter and lowest in summer. As an example, lettuce plants may be produced for $1.16/kg during the summer months, $3.11/kg in the fall and $4.29/kg over the winter (assuming yields are consistent over all seasons). The annual mean cost (12 month) at which lettuce may be produced is $3.10/kg. The annual mean cost represents the average cost of produce over 12 months/ 4 seasons of operation. Prices in northern greenhouses may be adjusted seasonally or maintained at the average cost throughout the year. In the latter case, summer profits would be used to balance winter deficits.

TABLE 18 : Unit production cost of local greenhouse produce in different seasons.

VEGETABLE	YIELD Kg/m2/m	SEASON SPRING	SUMMER	FALL	WINTER	6 MONTH MEAN	ANNUAL MEAN
GREEN BEAN	2.09	5.64	4.44	11.91	16.41	7.33	11.87
BEET	3.63	3.25	2.56	6.86	9.45	4.22	6.83
CH. CABBAGE	8.00	1.47	1.16	3.11	4.29	1.92	3.10
CUCUMBER	4.40	2.68	2.11	5.66	7.80	3.48	5.64
LETTUCE	8.00	1.47	1.16	3.11	4.29	1.92	3.10
GREEN ONION	2.00	5.90	4.65	12.45	17.15	7.66	12.41
SQUASH	0.65	18.14	14.29	38.29	52.77	23.57	38.17
TOMATO	2.55	4.62	3.64	9.76	13.45	6.01	9.78
TURNIP	5.25	2.25	1.77	4.74	6.53	2.91	4.73

TABLE 19 : Unit cost ($/kg) of local greenhouse versus imported produce.

VEGETABLE	WHOLESALE COST	IMPORT SUBS COST *	UNSUBS COST @	LOCAL 6 MONTH MEAN +	ANNUAL MEAN +
BUSH BEAN	1.76	4.85	7.85	7.33	11.87
BEET	2.00	5.09	8.09	4.22	6.83
CH. CABBAGE	1.07	4.16	7.16	1.92	3.10
CUCUMBER	0.74	3.83	6.83	3.48	5.64
LEAF LETTUCE	1.50	4.59	7.59	1.92	3.10
GREEN ONION	2.20	5.29	8.29	7.66	12.41
SQUASH	1.54	4.63	7.63	23.57	32.17
TOMATO	1.76	4.86	7.85	6.01	9.73
TURNIP	0.43	3.52	6.52	2.91	4.73

(* based on $3.09 subsidized freight rate)
(@ based on $6.09 regular freight rate)
(+ from Table 18)

Costs **are also considerably different when comparing a 6 month operating period with year-round production. In all cases, average unit costs** for a year-round facility are 60X higher than for a 6 month facility. These values should be considered when evaluating the scale of operation for northern greenhouses.

In Table 19, the unit costs of local produce (6 month and 12 month operation averages) are compared to unit costs of imported produce (subsidized and unsubsidized values). l-he values chosen **for import costs rePresent annual averages which take into account seasonal market price fluctuations (courtesy of Mr. Guy Labranche, H. Fine & Sons, Ottawa). Table 18 may also be used to compare imported costs** with seasonal local costs (spring, summer etc.).

The viability of northern vegetable production may now be evaluated using a variety of seasonal and annual comparisons :

[A] SUBSIDIZED IMPORT COST versus LOCAL PRODUCTION COST

Based on the yields obtained in 1986 trials, chinese cabbage and lettuce are the only two vegetables which can be locally produced on a year-round basis at a lower cost than subsidized imports.

If we **consider a 6 month operating period, beets, cucumber, and turnips may be added to lettuce and chinese cabbage as economically** viable crops for northern production.

Tomato production costs are lower than import costs during the spring and **summer seasons and may be considered for April to August cultivation. Bush beans are viable only as summer crops** in northern greenhouses.

The low yields of green onion, squash and other tested varieties such as kale, kohlrabi, radish, spinach and swiss chard render these vegetables uneconomical as candidates for greenhouse cultivation.

[B] UNSUBSIDIZED IMPORT COST versus LOCAL PRODUCTION COST

Unsubsidized costs represent the "true" cost of imports and it is worth comparing this value with local costs. Based on 1986 yields, beets, chinese cabbage, cucumbers, leaf lettuce and turnips could be produced on a year-round basis at lower cost than imports if unsubsidized rates were used.

If a 6 **month operational period were considered, all 9 major crops except squash could be produced more economically than import costs at unsubsidized levels.**

These results support the basic assumption that some level of vegetable production may be economically undertaken in all seasons. The improvement of economic viability for northern greenhouse production will be contingent upon a number of factors :

[1] Increased Production Levels

The yields obtained in Pond Inlet are based on small-scale trials under sub-optimal growth conditions. The improvement of crop productivity (increased Kg/m2) in larger, more technologically-efficient greenhouses will result in a reduction of local unit costs.

[2] Decreased Operating Costs

A reduction of operating costs may be realized through the increased utilization of available sunlight (thereby reducing costs of artificial lighting), reduced heating costs (reduced heat loss and decreased nighttime temperatures) and reduced labour costs (automation and hydroponics).

[3] Increased Import Costs

The gradual increase in freight rates increases the landed cost of imported produce and enhances the economic benefits of local production.

It is clear that winter costs are the primary factor responsible for elevating local prices above subsidized import costs. Freight subsidies were introduced as a method of reducing high northern food costs. In fact, artificially supported prices act as a dis-incentive to northern vegetable production by making competition difficult or impossible.

It is unclear whether vegetable consumption would remain at present levels if subsidies were lifted and Prices increased to "true" levels. It is conceivable that northerners might pay more for local produce of premium quality but this element cannot be adequately evaluated at present. One possible course of action which may be considered involves transferring those subsidies currently applied to fresh vegetables from Canada Post and transPort companies to northern producers permitting them to provide better quality, locally-grown produce at current prices.

Section 5-5 Value of Seasonal Cold Frame Produce

The growth trials conducted in the Pond Inlet cold frames were unsuccessful in 1986 and cannot be used in any economic assessment. It is possible however, to estimate what seasonal production values may be expected in future years by using production data collected in RankinInlet and Alexandra Fiord during 1982.(Romer,unpub.,Bergsma,1986).

The experiments conducted in RankinInlet were in cold frames identical to the ones constructed in Pond Inlet in 1985. The production yields presented in Table 20 are based on a 2 month outdoor growing season (July-August 1982). Operational costs for cold frame cultivation will be assumed to be the same as greenhouse costs during the summer season ($9.29/m2/m:Table 15).

$$\text{UNIT LOCAL COST (\$/kg)} = \frac{\text{Operational Costs}}{\text{Yield}} = \frac{(\$/\text{m2/month})}{(\text{kg/m2/month})}$$

Table 20 compares the local cost of seasonal cold frame produce with the current subsidized imPort costs.

TABLE 20 : Unit cost of vegetable produce grown in outdoor cold frame gardens (Based on University of Toronto production data : Rankin Inlet 1982) versus imported produce (subsidized cost).

	YIELD kg/m2/month	LOCAL COST ($/kg)	IMPORT COST ($/kg)
BEET	3.40	2.73	5.09
CH. CABBAGE	8,42	1.10	4.16
CARROT	1.68	5.53	3.64
KALE	3.78	2.46	4.54
KOHLRABI	3.92	2.37	4.56
LEAF LETTUCE	4.44	2.09	4.59
POTATO	2.50	3.72	3.64
RADISH	3.00	3.10	4.59
SPINACH	2.30	4.04	5.88
SWISS CHARD	3.80	2.44	6.95
TURNIP	3.80	2.44	3.52

Based on the production data gathered by the University of Toronto, it is apparent that seasonal vegetable production in cold frames is economically attractive for all varieties tested except carrot.

Local unit costs were from 32% (spinach) to 74% (chinese cabbage) lower than import costs, with an average reduction of 34% in unit price over all varieties tested. The higher cost of producing carrots locally would be easily offset by the savings generated from production of other less costly varieties (i.e. lettuce, spinach, turnip) if import Price levels were used for retail sales.

The cold frame production of vegetables may be used to :

1. satisfy annual requirements of cool weather storage crops such as carrots, potatoes and turnips (eventually onions and cabbage)
2. satisfy seasonal demands for fresh salad vegetables which may be marketed at substantially lower prices than Imports.

Section 5-6 Potential Production Schemes

Using the information in Tables 19 and 20, a number of potential production schemes may be evaluated for satisfying the current demands for the community of Pond Inlet. These are presented in Table 21.

SCHEME A

In Scheme A, the import and local production value of carrot, potato, cucumber, lettuce and tomato are compared assuming :

1. The annual requirement of carrots and potatoes are produced during the summer in cold frames.
2. Cucumber, lettuce and tomato demand is met through year-round production in a greenhouse facility.

In this case, the local production costs for these five vegetables would total $ 34,204.00/year or 30X more than the current import cost value of $ 26,125.00. This increase in cost may be a small difference to pay for improved quality of produce.

SCHEME B

In Scheme B, the same five vegetables are considered with a different set of conditions :

1. As in scheme A, the annual requirements of carrots and potatoes are produced during the summer in cold frames.
2. Cucumber, lettuce and tomato requirements are produced locally during 6 months of the year and imported over the winter months.

In this case, no cost advantage is derived by either 100% imported or 50X imported/ 50X local vegetable supply. There would however, be an improvement in quality of produce over part of the year if local production facilities are present. The partial production of selected, economically viable vegetables may be a suitable first step in establishing a commercial greenhouse industry in northern regions. The potential scale of such an operation in Pond Inlet is discussed in Section 7–5.

TABLE 21 : Potential production schemes for Pond Inlet

SCHEME A

	TOTAL KGS	TOTAL IMPORT COST	TOTAL LOCAL COST	
CARROTS	1,192	4,340.00	6,592.00	(It)
POTATOES	2,546	9,267.00	9,471.00	(*)
CUCUMBERS	560	2,144.00	3,158.00	(+)
LETTUCE	954	4,379.00	2,957.00	(+)
TOMATOES	1236	5,995.00	12,026.00	(+)
TOTALS		26,125.00	34,204.00	

(*) Seasonal Cold Frame Production and Storage (Table 20)
(+) Year-round Greenhouse (Table 18)

SCHEME B

	APRIL - SEPTEMBER			OCT - MARCH	
	TOTAL KGS	IMPORT COST [A]	LOCAL COST [B]	TOTAL KGS	IMPORT COST [C]
CARROTS	1,192	4,340.00	6,592.00		
POTATOES	2,546	9,267.00	9,471.00		
LETTUCE	477	2,190.00	916.00	477	2,190.00
CUCUMBER	280	1,072.00	974.00	280	1,072.00
TOMATO	618	2,998.00	3,714.00	618	2,998.00
TOTALS	5,113	19,867.00	21,677.00	1,375	6,260.00

Total kgs = 6,488

[Al + [C] Import Cost (12 months) = $ 26,127.00

[B) + [C] Partial Local/ Partial Import = $ 27,937.00

Section 6 Related Benefits of the Greenhouse

This section explores some of the social and indirect economic benefits of the research project for northern communities and peoples.

6-1 EMPLOYMENT AND TRAINING

One of the primary objectives of this project was to train local native residents in horticultural techniques and greenhouse operation. Two Pond Inlet residents became involved with the facility in 1986.

Asenath Pitseolak, a mother of two, was employed by the T.S. Co-op as a Horticultural Trainee in August (Photo 19). Over the course of the following months, she received training and assisted in all aspects of crop production and greenhouse management. Asenath, who had no previous experience in plant culture or laboratory procedures, learned rapidly and was soon able to carry out all routine cultivation, environmental monitoring and greenhouse operating procedures. By October, the role of the manager had become primarily a supervisory one. Since the departure of the author (manager) from Pond Inlet at the end of December, Asenath has continued to operate the greenhouse unaided, successfully producing crops, monitoring conditions and maintaining the winterized greenhouse.

Geela Anaviapik, a high school student, worked part time in the greenhouse during the summer months (photo 21). Geela assisted with crop maintenance (watering, thinning), harvest and data recording procedures.

As illustrated by these two individuals, employees in northern greenhouses may gain experience and benefit from training in a wide range of research and applied fields. This experience would contribute to expanding the individual's job skills and facilitate the acquisition of future employment. Having gained experience, horticultural technicians may in turn provide training for newer employees from other communities.

Since the gathering of edible native Plants and preparation of foodstuffs has traditionally been undertaken by native women, vegetable gardening as an extension of these traditional practices represents a challenging new employment opportunity for women.

Students would also benefit from a local greenhouse industry by receiving on the job training and employment in the summer months. A number of seasonal tasks which include soil collection and processing, greenhouse maintenance and repair and cold frame construction must be completed during the short summer season and would provide job positions suitable for students.

6-2 EDUCATION AND AWARENESS

During the course of the research project, a large number of local residents visited the greenhouse to satisfy their curiosity and evaluate the ‘new addition” to their community.

In many cases, visitors were somewhat skeptical prior to entering the greenhouse as the concept of growing vegetables in the Arctic is a new and unusual one. These feelings passed quickly however as visitors began to appreciate the colourful displays of crops and flowers, the interesting textures and flavours of fresh vegetables, the novel approaches to hydroponic crop production and the warm, sunny environment of the greenhouse (Photos 21, 22, 23).

Visitors particularly enjoyed the opportunity to be able to sample new vegetables such as chinese cabbage and kale or unprocessed vegetables such as spinach and green beans which are normally available as frozen or canned products. Some visitors returned frequently and were rewarded with samplings of recently-harvested crops or cut flowers to take home.

PHOTO 21 : Sumner student **Geela Anaviapik** holding turnips var. Purple **Top** White Globe (top).

PHOTO 22 : Richard Hunt with fresh-Picked greens **in front of the T.S. Co-op's Sauniq Hotel (bottom left).**

PHOTO 23 : **Sauniq** Hotel manager Anna **Koonoo** displaying fresh salad greens inside greenhouse (bottom right).

Northern greenhouses may contribute in several ways to increased awareness and education among local residents :

[1] Nutrition

By developing an appreciation for the taste and quality of fresh produce, northerners may be encouraged to increase the utilization of these foodstuffs in their diet. The introduction of varieties previously unknown in the north would contribute to expanding and diversifying the dietary base.

Although the nutritional components of northern versus southern produce were not analysed for this project, several factors support the use of local over imported produce :

(a) The low incidence of weeds and pests in arctic areas virtually eliminates the need to use costly and potentially deleterious chemicals (herbicides, pesticides and fungicides) required in southern greenhouses.

(b) Large transport distances require that imported produce be harvested from 2 to 3 weeks before it actually reaches the consumer. This contributes to a significant decrease in nutritional value, losing water soluble vitamins (i.e. Vitamin C) rapidly over several days.

in contrast, vegetables grown locally may under most circumstances be purchased the same day as they are harvested thus retaining their high quality nutrients and fresh flavour. Fruits such as tomato which are ripened directly on the vine also benefit from improved taste and texture.

[2] Education

Through involvement with the school system, greenhouses may act as educational tools for teachers and adult educators. During 1986, a large number of young students visited the greenhouse both in organized classes and on their own. Students examined a wide range of plant and vegetable varieties for the first time and iearned the principles of plant growth.

The greenhouse was also used in conjunction with a commercial cooking class in the fall.Local participants benefited from this course by learning many potential uses and new methods of preparation for vegetables and herbs.

The affiliation of greenhouses with educational establishments such as Arctic College and the proposed University of the North could serve to initiate research programs and create centers for the development and advancement of northern agriculture and technology.

The University of Alaska for example, has a large agricultural program which operates in conjunction with Alaska's commercial farmers, providing them with assistance, as well as developing new varieties of crops and improved techniques of production suited to the northern climate.

[3] Local Small-Scale Gardening

The presence of a local greenhouse industry may also stimulate local interest in "kitchen gardening" and related home improvement activities (housePlants). Small-scale home gardening and production of vegetables is a very enjoyable and rewarding practice which may be undertaken at very little expense during the summer season.

In Rankin Inlet, the desirable quality and variety of crops produced at the Keewatin Gardens encouraged *numerous* families to construct and tend their own backyard cold frames. Several enthusiastic residents extended production into the winter months by establishing small hydroponic gardens indoors.

Local gardeners were encouraged in their efforts by the author who provided them with practical advice, seeds and fertilizer. A guide entitled " A Guide to Small-Scale Gardening in the Keewatin and Other Low Arctic Communities" (Romer 1980) was circuited to provide information on simple vegetabie production techniques.

6-3 Local Economy

The introduction of a greenhouse industry would expand the economic base of northern communities. The cultivation of vegetables is a "non-traditionai" practice which is currently not carried out in any form by northerners. The initiation of local crop production facilities would not eliminate or replace any existing businesses or 'cottage industries within the community. Instead, a completely new eiement would be introduced into a generally limited local economy.

In **addition, a number of small businesses may be expected to develop around or benefit from** the presence of a local **facil**ity. These may include :

[1] Food Processing

Businesses concerned with the packaging, canning, freezing or processing of produce (sauces, soups etc.) prior to retail distribution may be initiated. Considering the current demand for novelty food items, large **faci**lities may consider exporting **"organic** arctic produce" to **exclusive** restaurants and **speciality** shops **in** southern centres.

[2] Tourism

The presence of greenhouses in the north with their new and exciting technology **qualifies** them as tourist attractions. Visitors to the **Sauniq** Hotel in 1986 were pleasantly surprised to see fresh vegetables and flowers growing in such a remote northern location (Photos 24, 25). In addition, guests at the hotel enjoyed freshly-harvested salads for dinner.

[3] Floriculture

Potted **houseplants,** cut flowers and even **seedl**ings for summer gardeners may be produced and distributed by enterprising local individuals as a form of part-time or 'hobby" industry.

For example, John Henderson, a local Pond Inlet resident, maintains a small seasonal greenhouse as a part-time business and hobby. In addition to producing hydroponic cucumber, tomato and lettuce, John has SUPPlied local residents with flowerpots and potting soil which he has prepared from local peat, and sand deposits for several years. It is this author's belief that small businesses such as John's increase public awareness and diversify the local economy and should be actively supported!

[4] Research

Greenhouse projects are potential testing grounds for research and development in the fields of alternate technologies (waste heat utilization, solar energy and wind power) and agricultural practices (cold climate crop engineering, hydroponic culture). Studies related to frost tolerance in crops and low temperature growth and **productivity** in plants may have significance for global agriculture as well. Canadians **should** follow the example of other **circumpolar** nations and expand the scope of agricultural research and development in northern regions.

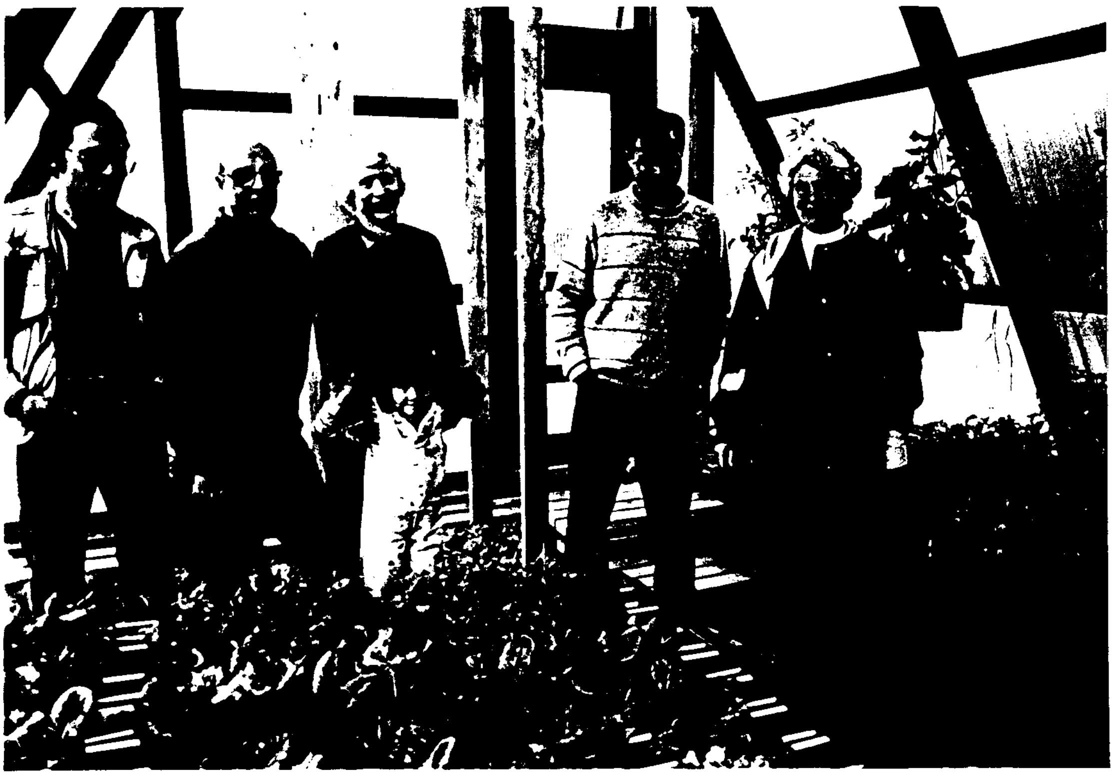


PHOTO 24 : Visitors enjoying greenhouse **sunspace** and produce. (From left) Joe **Enook, Commissioner** John Parker and **Mrs.** Helen Parker, Local **MLA** Dennis Patterson (his daughter in front) and Mrs. Sheila Day.

PHOTO 25 : Hotel guests Michael **Kozicki** and Chris Latchem preparing to eat freshly-Picked greenhouse salad.

Section 7 Conclusions and Recommendations

7-1 Conclusions

As part of an effort to reduce high food costs and increase self-sufficiency of northern communities, the present study re-examined the potential for vegetable production in arctic regions.

A variety of crops were tested over 3 seasons of 1986 in a small solar greenhouse constructed to include a heat storage foundation and solar-collecting panels. Annual and seasonal operating costs were determined for a northern greenhouse facility and cost estimates of local versus imported produce were made.

Results showed that year-round production of selected temperate vegetables is technically and horticulturally feasible when efficient systems of climate control, insulation and plant growth are incorporated into structural designs.

Economic viability was demonstrated for certain vegetable varieties especially if production is limited to spring, summer and fall seasons since a large proportion of the annual operating budget is spent to maintain artificial lighting systems. Costs should decrease dramatically with more efficient use of available sunlight and/or in the less severe climate of lower latitudes.

7-2 Future Directions

Based on the results of the Pond Inlet project, a number of recommendations can be made with respect to future development of northern greenhouses.

7-2-1 GENERAL RECOMMENDATIONS

Development of agricultural programs in the Arctic should follow a slow, integrated appreach which combines hands-on experience with continued research and development. A gradual , incremental process of trial and evaluation will more likely succeed in realizing local vegetable self-sufficiency than will an immense capital drive of untested technology into unprepared communities.

It has been clearly demonstrated that the success of new northern ventures is contingent upon active community acceptance and participation. It is strongly recommended that subsequent projects undertake a collaborative approach to development with existing community organizations and local residents. Involvement should include employment and training of native residents, encouragement and assistance of local gardeners and educational tours and courses.

Efforts to date have demonstrated the viability of local production on a smal l-scale basis. It is now necessary to increase the scale of production to gain experience and permit evaluation of a commercial-scale operation. Future projects should be designed with the intention that they be self-sufficient, operating as businesses, not solely as research faci l ities. In this way, models and projections can be replaced with concrete operational data and experience.

Early projects should not attempt to attain 100Z substitution of all imported varieties immediately. Southern greenhouses concentrate on the production of one or two different plant varieties which have simi lar growth conditions and requirements. A northern faci l ity should first be concerned with producing varieties which have an establ ished popularity, have been Proven to be horticultural ly viable in the Arctic, have the greatest economic potential for success (high yields, high current market value) and have the greatest potential for improvement in quality and nutritional value over presently-avai lable produce.

After having established economic viability and operational experience with a few varieties, expansion to meet current demands for most perishable produce and introduction of new vegetable varieties may be considered.

A comprehensive northern production facility will need to expand along two fronts :

[1] The <u>greenhouse production</u> of fast-growing, high-yielding and cost-effective crops such as cucumbers, tomatoes and lettuce on a year-round basis

[2] The <u>seasonal outdoor production</u> of cool weather storage crops such as cabbage, potato, carrot and onion. Two design models for such a facility are proposed in Section 7-4.

<u>Research and development</u> must be continued before self-sufficiency in vegetable production can be realized in the north. Although considerable information is currently available in the fields of greenhouse technology and plant cultivation, very little is applicable or has been tested in severe climates such as the Arctic. Research areas should include :

- Investigating alternate heat and power sources (solar, wind, water, waste heat)
- Designing and testing heat capture and storage systems and methods for reducing heat loss.
- Design of hydroponic and related plant product on techniques applicable to northern facilities.
- Bioengineering research : developing varieties tolerant to cold temperatures, frost and extended day length. Developing edible tundra species into productive northern cultivars.
- Market research : testing new varieties and new methods of processing them to increase public utilization and awareness.

The design of northern agricultural facilities should incorporate information gathered from (1) previous northern research projects, (2) applicable southern research projects (Brace Research institute, McGill University; Agriculture Canada Greenhouse Research Branch) and (3) other circumpolar research and commercial projects (USSR, Scandinavia and Alaska).
An effective means of optimizing the collection and distribution of information and avoiding the duplication of efforts is the establishment of an Arctic Agricultural Research Centre. This idea is discussed in Section 7-3.

7-2-2 DATA BASE REQUIREMENTS

Future development of large-scale commercial greenhouses must be preceeded by a thorough evaluation of technical, horticultural and economic parameters. The major components Of this data base will include assessment of market potential as well as scientific and economic feasibility.

[A] MARKET POTENTIAL

An evaluation of the current and projected market size will determine the scale of operation for any community project. This will involve :

- **evaluating current and projected levels of consumption.**
- isolating most important varieties based on demand and economic cost effectiveness.
- **examining seasonal patterns of demand and consumption as they affect production.**
- identifying markets **for the sale of produce and methods of distribution available.**

[B] ECONOMIC FEASIBILITY

A thorough cost-benefit analysis must be conducted using different scenarios in order to determine the best course of **development. Included in such a study are :**

[1] Start-up Costs

- **purchase or lease of land**
- **purchase cost of structure (design, manufacture) and control systems**
- transportation costs of facility to site (sealift, air cargo, local transport)
- **labour costs for construction : site preparation**
  soil preparation
  assembly

[2] Operating Costs

- labour costs : horticultural technicians (full time)
  technicians, students (part time)
- energy and utility costs : heating costs
  electricity
  water and taxes
- materials : seeds, fertilizers, tools
  shipping costs for materials
  replacement costs (lights and motors)
- storage and processing costs : packaging
  cold storage
- administrative costs : advertising, accounting
  office overhead

[3] Fringe Benefits

- reduced spoilage of foods
- premium prices for high quality produce
- elimination of transport subsidies

A number of cost-benefit schemes must be developed for various design options (technical and horticultural) in order to identify the best course of development. The projected production costs and revenues for each alternative must be weighed against the current retail situation :

- current freight costs and effective subsidies
- wholesale costs and retail value of produce
- projected revenues

[C] SCIENTIFIC FEASIBILITY

A thorough examination of the technological needs and resources available to the project would include :

- **an up-to-date synopsis of greenhouse technology, past experiences and developments in Canada and abroad.**

- **assessment of climatic features and environmental factors of proposed locations : frost free period, temperature ranges, wind activity and precipitation.**

- **identification of available local resources and raw materials:**
  - **quantity and quality of water**
  - **potential sources of waste heat**
  - **sources of power**
  - **soil** reserves - **quantity and quality**
  - **heat storage mediums - stone, gravel**
  - **labour resources - qualified/unqualified**

- **investigation of potential locations :**
  - **degree of possible shading in all seasons**
  - **possible orientations**
  - **shelter from prevailing winds**

- **consultation with engineers, horticulturalists and technologists :**
  - **evaluate alternate sources of power**
  - **different possibilities for growing systems**
  - **design options** for structure

7-3 Technology Transfer and Training

The development of northern production facilities in other communities and the improvement and expansion of existing facilities would best be directed from a central Agricultural Research and Training Centre. The proposed centre could be developed along the lines of the University of AlaskaDs Agricultural Experiment Station in Fairbanks, Alaska (University of Alaska, 1980).

Research at this centre has involved the conventional field culture of crops, the development of suitable vegetable varieties for northern regions and work on controlled environment greenhousing and horticulture of vegetables and ornamental.

In Canada, such a centre could be affiliated with either Arctic College *or* the proposed University of the North. Areas of potential involvement would include :

[A] Collection and Distribution of Information

- public relations and promotion of greenhouse projects in northern communities
- data pertinent to operation of existing projects
- gardening guides for local residents
- greenhouse operating manuals for projects
- annotated bibliographies of related literature
- results of horticultural variety tests
- general interest information (houseplants, seed sources)

[B) Research and Development

- design and testing of new technological and horticultural systems and methods
- collecting feedback from existing projects and directing development of future ones
- developing and testing new varieties of vegetables and improving cultivation practices
- performing soil analyses and providing fertilizer recommendations to soil-based projects

[C] Training

- theoretical and applied training of prospective greenhouse technicians and summer students
- developing training manuals and operating manuals for use in northern projects
- providing the services of a "travelling horticulturalist" who could visit projects and act as a central authority for providing advice and information
- staging of workshops on new developments
- offering courses in horticulture, Botany and related sciences

The proposed research centre need not be an independent facility but may comprise a part of a commercial operation. In this way, new developments may be immediately tested at a commercial level.

7-4 A Design Concept for a Northern Production Facility

Considerable information was obtained during the first season of operation at the Pond Inlet Gardens. Summary evaluations of technical performance during this trial period have been presented in Sections 3 and 4 of this report. Based on these evaluations, a modified design may be proposed for a northern production facility. The comprehensive facility will comprise two parts :

1. a greenhouse for year-round production of vegetables
2. cold frame gardens for the seasonal production of cool weather storage crops.

The proposed designs are presented in Figures 21, 22 and 23 and major points summarized below.

7-4-1 SOLAR GREENHOUSE

The location of the greenhouse must be selected to provide an unobstructed exposure to sunlight at all times. Orientation should be towards the southern hemisphere.

[A] Structure

The structure should be divided into separate production compartments permitting the operator to adjust and optimize growing conditions for each crop. This design feature also permits rapid isolation and treatment of pests and pathogens.

Entry into the greenhouse is through an utility/office room which acts as an effective airlock and may serve as office area, storage space for materials, headhouse for preparing seedlings and harvesting plants, warming room for water tanks and hydroponic reservoirs and control centre.
The greenhouse may also be joined to an existing structure (office building, commercial outlet) by means of an insulated corridor and may share a common heating source.

The heat storage foundation remains similar to the existing structure with sand or crushed gravel as a storage mass and heat delivery through plastic corrugated drainage tubing. The storage structure acts as a supporting frame for the greenhouse and must be very well insulated to minimize heat loss to the exterior.

FIGURE 21 : A proposed design for a northern greenhouse based on the Pond Inlet facility. (Vertical cross-section of structural and production facilities).

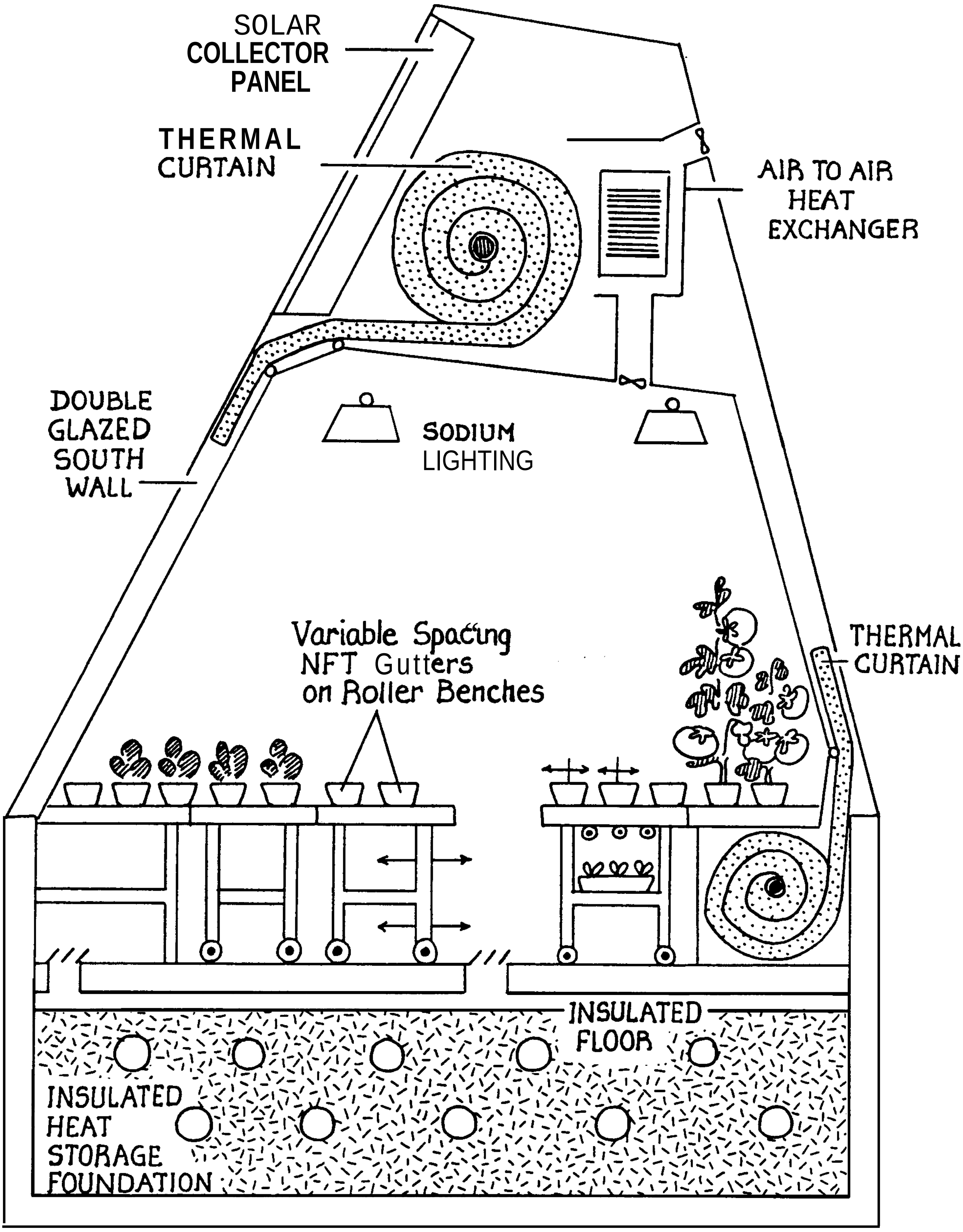


FIGURE 22 : A proposed design for a northern greenhouse based on the Pond Inlet facility. (Horizontal cross-section of structural and production facilities).

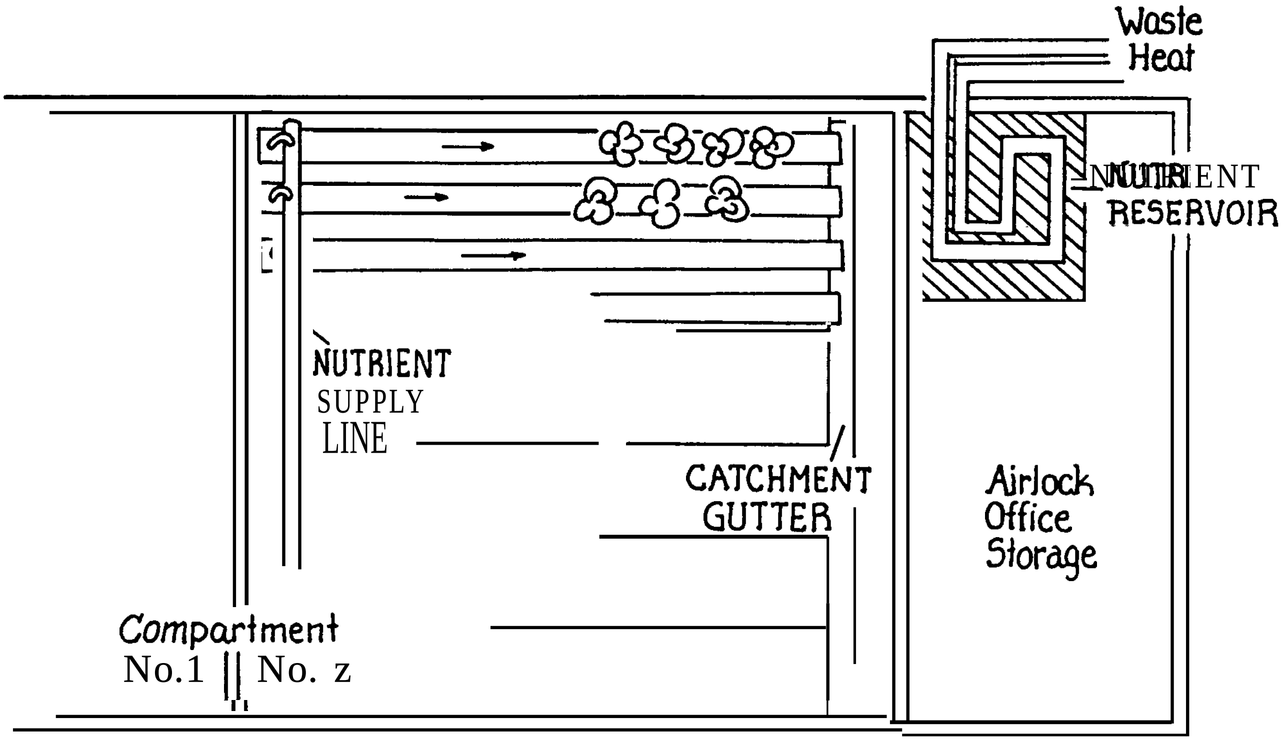
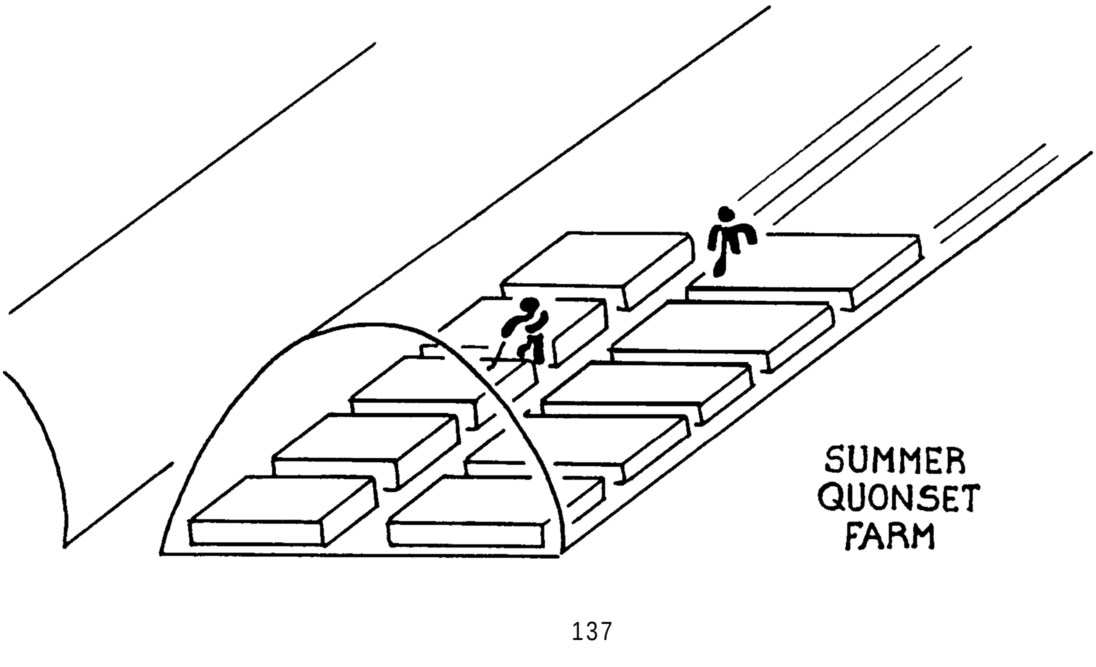


FIGURE 23 : Proposed design of a seasonal outdoor cold frame farm for northern regions.



The addition of an insulated floor above the storage mass will permit the controlled release of heat into the greenhouse through thermostatically operated dampers. This modification will also eliminate heat loss from the greenhouse into the storage mass during winter months. Heated air is delivered into the storage mass from the solar collector panels and the greenhouse peak.

At high latitudes, the design includes an insulated roof upon which can be mounted the solar collector panels and air-to-air heat exhanger. The design of the solar collector may incorporate a system for heating the NFT nutrient reservoir as well as the storage mass and greenhouse air.

The glazing panels and insulation of the frame are combined into one unit. Two layers of acrylic glazing are present and are well sealed to minimize heat loss from the greenhouse. The system of insulation comprises two parts:

[a] A moveable thermal blanket is situated between the two layers of glazing and may be rolled up or down depending on the availability of sunlight. These thermal blankets may be stored in the roof area or under the growing benches in sealed compartments.

[b] An exterior winter blanket which covers the entire structure and provides additional protection from the cold is added when daylength becomes too short.

Ventilation is provided by means of passive vents, circulating fans and exhaust fans. An air-to-air heat exchanger ensures adequate gas exchange while minimizing greenhouse heat loss during the cold months. Incoming air may also be conditioned (warmed) by passing it through the heat storage mass at certain times of the year.

Heating is provided from solar and waste heat sources. Backup heating may be generated by using a propane heater which would also increase C02 concentrations within the greenhouse.

Lighting is provided by high intensity sodium bulbs supported on adjustable booms above the growing beds.

All environmental conditions within the greenhouse may be controlled by a greenhouse computer system (DGT,Priva) to provide accurate control of all parameters and alert operators to any irregular events.

[B] Plant Production Facilities

Plants are grown in NFT hydroponic culture on a series of roller benches which maximize available space in the greenhouse. The benches provide a growing surface as well as storage space below.

The nutrient solution for plants is heated using waste heat (heating coils in the reservoir) and nutrient and pH levels are automatically adjusted using 'read and feed" analyzers. Separate nutrient reservoirs are maintained for each crop and/or compartment to permit adjustments according to plant variety and stage of development.
NFT gutters are of variable sizes and may be adjusted to provide the most desirable spacing. Nutrient solution flows into the gutters through a common feeder line and is collected along a common catchment gutter.

7-4-2 COLD FRAME GARDENS

During the summer season, cool weather crops such as cabbage, carrots, potatoes, turnips and lettuce will be produced in a modified 'Quonset farm" illustrated in Figure 23.

The proposed structure consists of soil-filled cold frame gardens with insulated bases (Rankin Inlet design) protected by a Quonset style greenhouse shelter. This structure can be obtained at a landed cost of approximately $ 20.00/ m2 (Harnois Industries Econo-tunnel). If the cost of the cold frame materials is included, the effective capital investment is in the region of $ 40.00/ m2.

These structures may be set up in units of 105 m2 or 210 m2 of growing space. Ventilation is passive through gable end windows and side vents. A small auxiliary heating source may be considered for cool periods during the spring and fail. This could effectively increase the growing season by 3 to 4 weeks.

Both the initial construction and subsequent operation are labour intensive and would provide an excellent employment opportunity for summer students and horticultural trainees. Seedlings for the seasonal crops should be pre-germinated inside a greenhouse facility approximately 6-8 weeks before transplanting into outdoor cold frames. The watering, fertilizing and crop maintenance is then undertaken by greenhouse helpers.

7-5 Scale of Operation for Pond Inlet

Using the production data from Tables 18 and 20, it is possible to obtain a conservative estimate for the scale of operation which would be required to supply selected vegetables to the community of Pond Inlet at current levels of consumption. This data is summarized in Table 22.

TABLE 22 : Scale of production faci l ity required to meet current consumption levels of selected vegetables in Pond Inlet (year-round operation).

	CONSUMPTION kg/year	PRODUCTION kg/m2/yr	AREA REQUIRED meters2
GREENHOUSE			
TOMATO	1236	30.6	41
CUCUMBER	560	52.8	11
LETTUCE	954	96.0	10
		TOTAL [A] =	62 m2
COLD FRAMES		kg/m2/season	
POTATO	2546	5.0	509
CARROT	2364	3.4	690
		TOTAL [B] =	1199 m2
TOTAL [A] + [B] =	7660kg		1261 m2

Based on the projected figures, it would require approximately 62 square meters of greenhouse space to meet current demands for cucumber, tomato and lettuce in Pond Inlet. These three vegetables represent one quarter (by weight) of the vegetables consumed annually in the community.

in contrast, a total of 1199 square meters of cold frame gardens would be needed to produce the annual potato and carrot requirements of 4910 kgs (47% by weight of vegetable consumption) .

Conceivably, the current Pond Inlet greenhouse with 13.4 m2 of growing space, could produce the community's annual requirements for either cucumber or lettuce!

7-6 Future Utilization of the Pond Inlet Greenhouse

The-Pond Inlet Gardens facility provided the experimental "testing grounds for examining the viability of northern vegetable production. Although the facility demonstrated the capability of year-round operation, the very small growing area and proportionally high labour costs make it unsuitable for present use as a retail production facility. Instead a number of potential alternatives exist :

[A] 1987

It is recommended that the greenhouse continue operating on a full time basis in 1987 in order to :

1. collect technical and horticultural data over one complete year with systems 100% operational. (The greenhouse was under construction and systems were frequently modified in 1986).
2. observe and evaluate the effectiveness of the solar collector and heat storage foundation as a heating system during the spring and summer seasons.
3. compile more accurate information concerning energy requirements, production costs and horticultural trials over the course of a complete year.
4. re-evaluate the performance and production capacity of outdoor facilities under better climatic conditions than were encountered in 1986.

[B] 1988 Onwards

Following this period, the facility should continue operation on a seasonal basis in the spring, summer and fall months. The higher operating costs and relatively small growing space suggest that winter operation is impractical.

The high cost of labour associated with operation of this facility (see discussion Section 5-2-4) may be altered by converting the position of greenhouse technician to a part-time one (or shared with other duties in the hotel or retail store) . During the summer season, students may be enlisted to assist the technician in production of crops in outdoor and indoor facilities.

The greenhouse facility should concentrate its vegetable production activities in the summer tourist season to provide visitors with fresh salad greens and an interesting attraction. A section of the greenhouse may be converted into a 'sun-space" where guests may relax in a warm and colourful environment. A walk-in corridor linking the greenhouse and hotel would greatly facilitate access.

The greenhouse may also continue to act as a small-scale testing centre by examining new varieties of vegetables, testing new techniques and monitoring costs and energy requirements in different years.

The greenhouse has potential for conversion into a seedling germination and pre-growth area for a larger scale cold frame operation such as the one described in Section 7-4-2.

The current technician, Asenath Pitseolak, may in the future play a role in training other greenhouse workers or summer students. The facility may also be used by the local school to demonstrate scientific principles and/or as a centre for special projects.

Should the Co-op desire to use this facility for retail production, the best course of action would be to concentrate on one or two vegetables with similar growth requirements. Tomatoes and cucumbers are the best choices as they require less care and are longer lasting producing only 2 to 3 crops per year. Alternately, the fast growing-and highly productive lettuce and chinese cabbage may be considered. In either case, the growing beds will require some degree of modification to optimize production. If winter operation is expected, the installation of an air to air heat exchanger or utility corridor between the hotel would be required to improve gas exchange and circulation of air inside the greenhouse.

The author sincerely hopes that the Pond Inlet facility will continue to operate in some capacity and further contribute to local interests in either a business or recreational capacity.

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