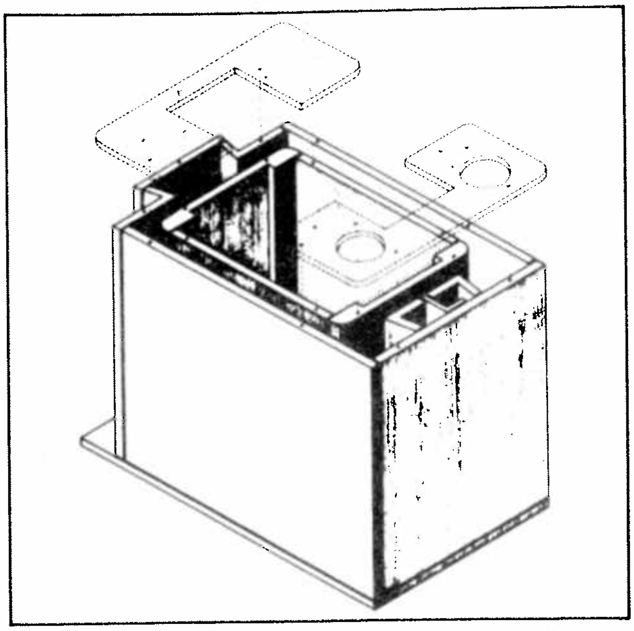

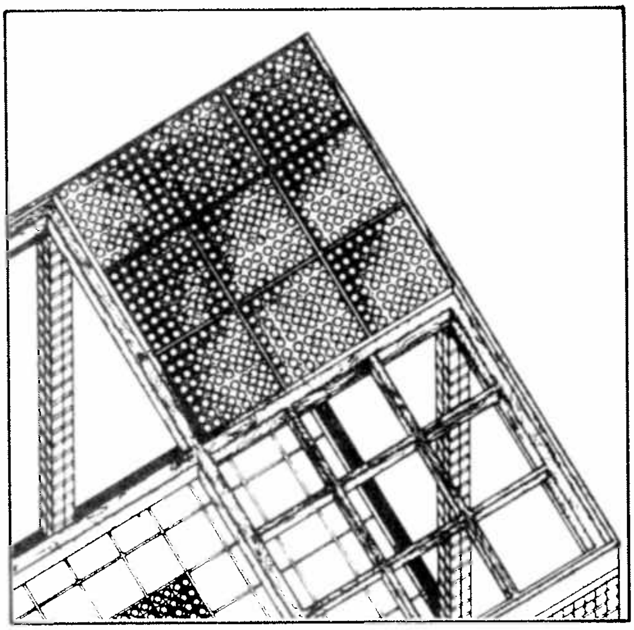

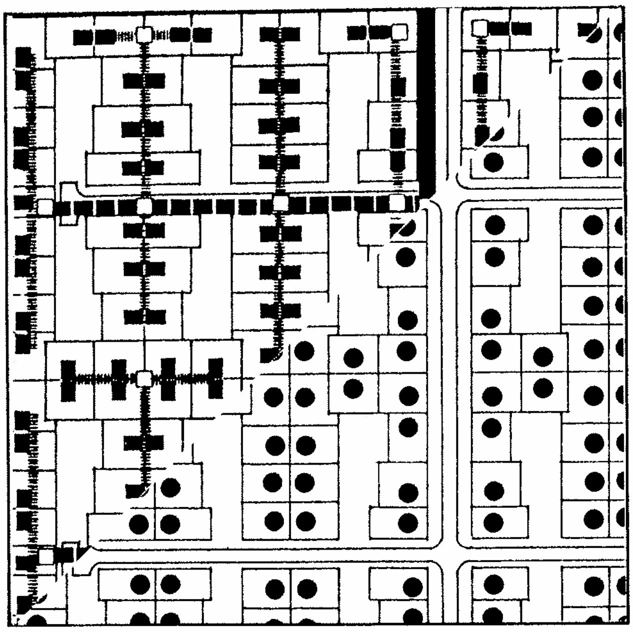

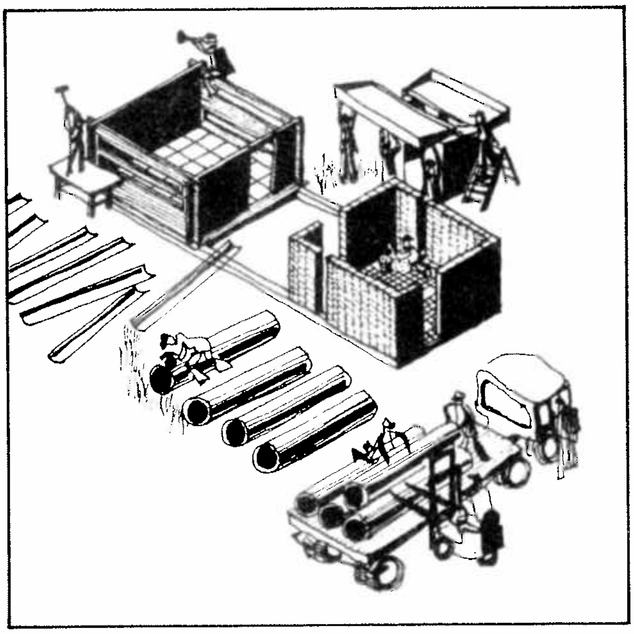

ENERGY CONSERVATION IN GREENHOUSES
THROUGH THE USE OF RETRACTABLE INSULATION

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Witold Rybczynski & Vikram Bhatt

Research Paper No.4 July 1980

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Originally prepared as the final report of a research project,
May 29, 1979 - July 29, 1980,
performed under an Agricultural Engineering Resource
& Development Grant (AERD) No.07/010-SZ-8-3001
Contract No. 1SZ79-00052

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ACKNOWLEDGEMENTS

We would like to acknowledge the excellent cooperation of the Department of Physical Plant of McGill University, which provided the use of a greenhouse for testing purposes, in particular Messrs.P.S.Keough and W.Downing. Prof.J.E.Lewis of the Department of Geography and M.R.Foisy of Hydro-Québec assisted by loaning monitoring equipment. Mr.Lee Ellison of the Stauffer Chemical Company was particularly helpful in expediting rapid shipment of thermal curtain material. The Office of Industrial Research, and Mrs.Carolyn Draper of the School of Architecture, efficiently administered the financial aspects of the project.

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ILLUSTRATIONS

1. INTRODUCTION

Heat loss from a greenhouse is a function of a number of factors, but is chiefly the result of the difference between the inside and the outside temperatures. Three modes of heat travel (radiation, convection and conduction) are affected to varying degrees by this temperature difference and account for different proportions of the overall heat loss (radiation-15%, convection-25%, conduction-60%). Any attempt to reduce heat loss from greenhouses must address all three modes.

The high conduction losses of greenhouses (both glass and plastic) are the result of the poor thermal insulation of the envelope. The first property of greenhouse insulation must be thermal resistance, and secondly the ability to reduce radiation and convection losses; the former is normally achieved by some degree of reflectivity, and the latter by "air tightness". However, since during the day solar energy is a key ingredient for plant growth, and since materials that combine thermal resistance and high light transmissivity are not presently available, any nighttime thermal insulation must be capable of being retracted during the day.

A number of retractable insulation systems are currently on the market in North America. These are characterized by high quality and high cost, and have been developed for flower producing greenhouses, the economics of which are significantly different from crop greenhouses, the subject of this research project.

The principal costs involved in operating a Canadian crop greenhouse are: a) capital cost, b) heating cost, and c) labour cost. According to a 1975 Statistics Canada report, these costs on an annual square foot basis were $3.34, $0.26 and $0.29 respectively. If the growers investment were to be amortised at 10% yearly over a 20 year period, he would spend $2.60/m^2 on heating, $2.90/m^2

on labour costs, and $3.34 on carrying charges. It is clear that heating represents a significant fraction of the operating costs, and that any saving in heating can therefore be reinvested in upgrading the greenhouse, or in mechanizing operations and reducing labour costs.

A simple example illustrates the economics of retractable greenhouse insulation. Assuming that an RSI 0.5 curtain reduces the heat loss by about 50%, the savings expected would be about \$1.30/m^2. In order for this insulation to be economically attractive it must pay for itself in a relatively short time, and should not therefore cost more than about \$13.00/m^2. This is considerably less than any of the commercial systems currently on the market which cost from $15 to $25 per square metre.

Preliminary calculations as regards cost effectiveness indicate that an RSI 0.8 thermal curtain can achieve up to 30% energy savings, which would permit an investment of about \$10/m^2, assuming a five year pay back period. Thus the following criteria have been adopted for the development of a low cost retractable insulation system.

a. Installed cost to be less than \$10/m^2.
b. The final thermal resistance of the greenhouse and curtain should be about RSI 0.8 (R5).
c. The low cost curtain system should be simple enough to be assembled and installed by the grower himself.
d. The system should avoid condensation problems.
e. Storage of the open system should not unduly shade plants below.
f. The system should be adaptable to various greenhouse configurations and sizes.

2. SYSTEMS AND HARDWARE

The first stage of the project involved identifying existing hardware and movement systems which could form the basis for a retractable insulation system. Initial research had identified four general categories of retractable systems:

a. Folding accordion
b. Roll-away blanket
c. Sliding panels
d. Suspended curtain

Manufacturers were contacted with an aim of identifying appropriate hardware. Three types of firms were investigated: first, manufacturers of hardware for sliding, rolling and folding doors and shutters, second, manufacturers of retractable insulation systems for domestic use, and third, manufacturers of sun shades and screens specifically designed for large greenhouses (see Appendix V).

The general conclusions were as follows.

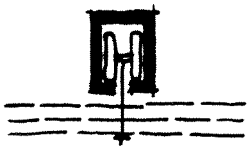
Overhead and folding door hardware is suitable for rugged and heavy performance but difficult to adapt to light, precise tasks. Furthermore, the problem of air tightness is virtually impossible to solve with these type of systems. Sliding doors and shutters are more suitable to tight sealing but generally too expensive to consider for this application. Of all the types of systems looked at the most promising seemed to be lightweight blinds and curtains.

There are a number of recently developed domestic thermal shade systems on the market (primarily in the United States). Though these have somewhat different characteristics than would be found in a greenhouse system (they are small, vertical and high cost), it was felt to be worthwhile to see if they might be modified. Of ten systems surveyed three (all of roller blind type) could have application were it not for the too high cost.

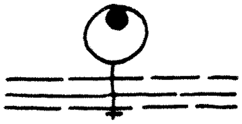
The greatest potential for adaptation of existing hardware lies, not surprisingly, within the greenhouse industry itself.A number of systems presently exist that solve the problem of retractable screens, either for sun shading or thermal insulation. The majority of these have been developed for flower producers and are too expensive to be adapted to crop greenhouses, though they do exhibit the general principles of thermal curtains.

Having identified screens or curtains as the most likely type of retractable insulation, four generic types were available.

a. Track supported
b. Cable supported
c. Cable suspended
d. Multi-cable


Track supported


Cable supported


Cable suspended


Multi-cable

Track-supported systems (e.g.Simtrac, Stuppy) are commonly used to support greenhouse shading systems. They are characterized by high quality (nylon rollers, extruded aluminum tracks) and relatively high cost (\$12-\$16/m^2 for tracks only). The installation is relatively complicated as the tracks must be suspended from the roof at intervals. These systems are not usually air tight.

Cable supported systems (e.g.Ickes-Braun) are considerably cheaper than track supported since the wire or filament costs less than \$0.16/m, whereas aluminum track is more than \$2.16/m. The main advantage of cable supported systems is their simplicity and lack of hardware. Cables can easily span most greenhouse widths. The main disadvantage is the inappropriateness of the system when more than one layer of curtain is used, since the cable interferes with proper hanging.

Cable suspended systems (e.g.Roll-Out) avoid the high cost of tracks and are able to overcome the disadvantage of cable supported systems by hanging the curtain below the cable. Although this introduces additional hardware in the form of hangers, it avoids contact between the cable and the multiple layers of curtain. Moreover, the curtain tends to fold naturally in accordion-like folds.

The multi-cable system (no commercial manufacturers known) is a variant on the cable supported type adapted to multi-layers. Each curtain layer has its own supporting cable, thus eliminating the bunching that occurs when more than one lyer is supported on a single cable. The additional cost of multiple cables is offset by the lack of hangers or curtain spacers.

A thermal insulation system based on the cable suspended type has been designed and tested (see Chapter 3). The multi-cable type has also been investigated and is described in more detail in Appendix II.

3. TEST INSTALLATION

The main purpose of this project was "to design and build an optimal system in prototype form which will allow performance studies to be carried out". The reason for this stage of the project is that very little empirical data exists as to the performance of greenhouse insulation systems. Most of the data on thermal performance has been developed for solid buildings and cannot be adapted to the greenhouse environment. Although it would be relatively easy to determine the thermal resistance of the insulation curtain, there is no data available as to the infiltration rates that should be assumed for such a system, while at the same time most experts agree that reduced infiltration will certainly be one of the chief benefits of a retractable insulation system. It was found that manufacturers literature neglected to give overall thermal performance of curtain systems, and highlighted, rather, the theoretical R-value of the matrix itself.

Existing Greenhouse

The test installation was located in a greenhouse belonging to McGill University and situated on McGregor Street on the downtown campus. The greenhouse is part of a larger structure being located at one extremity, and has three exposed walls and one interior wall which was insulated for the duration of the experiment. The greenhouse is a traditional single glass on steel frame (see Figs.1 & 2) spanning 6.32 m and 7.86 m long. The original heating system was hot water carried through overhead pipes. This system was disconnected since not only would the pipes have been outside the curtain, but the quantity of heat input would have been impossible to measure. The floor of the greenhouse is earth.

The greenhouse is situated away from large buildings or trees, a fact which, it was hoped, would contribute to stable nightime temperatures (see Fig.1).

Interior view showing steel structure, eaves vent and overhead heating pipes.

Exterior view along McGregor Avenue.

Fig. 1

EXISTING GREENHOUSE - Interior and exterior

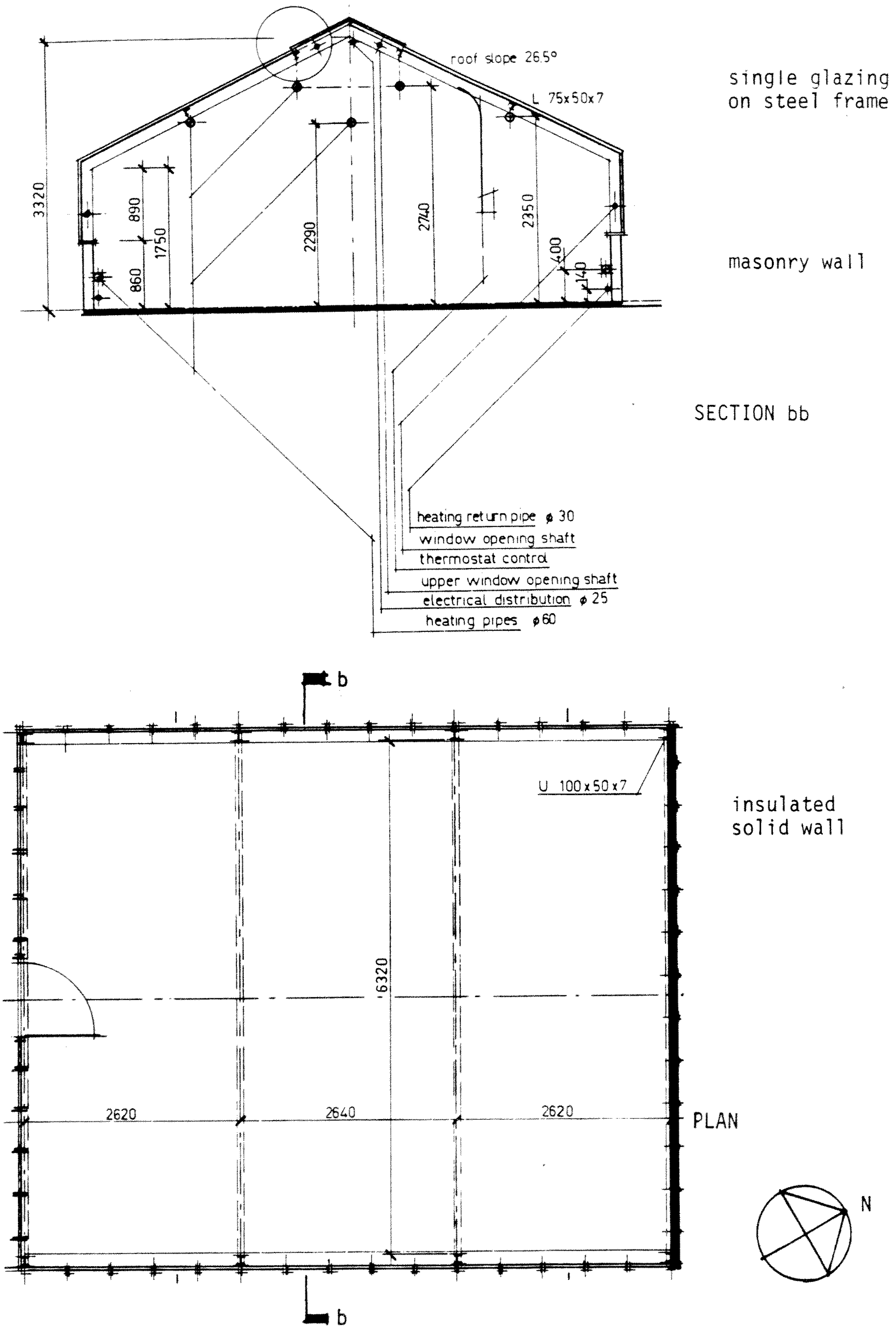
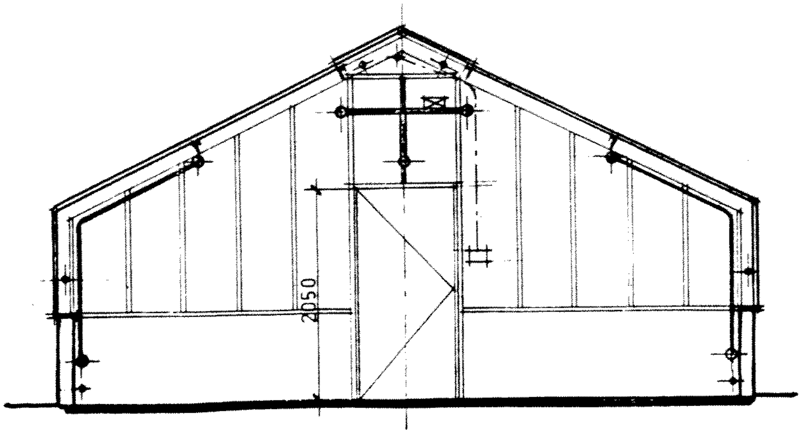
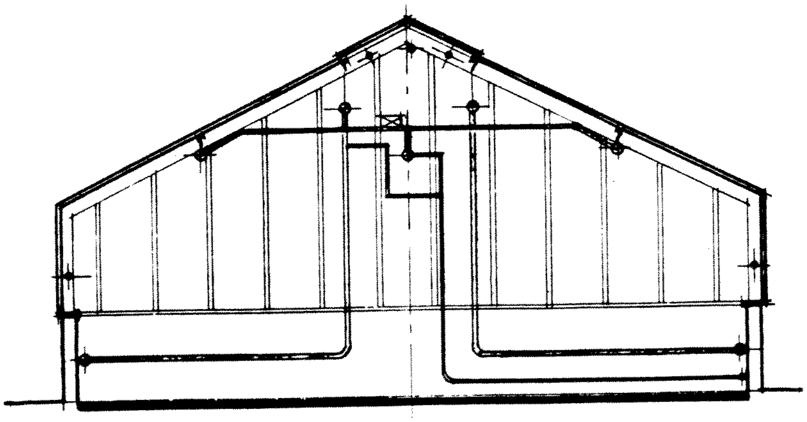


Fig. 2

EXISTING GREENHOUSE - PLAN AND SECTION



Interior elevation looking south west



interior elevation looking north east

Fig.3

EXISTING GREENHOUSE - ELEVATIONS

Thermal Screen Material

The main component of a screen or curtain system is the matrix or screen material. There are currently a limited number of options on the market. Some researchers are working with screens of transparent polyethylene (Centre de développement des cultures abritées, ministère de l'agriculture, Chateauguay, Québec). This material has no resistance to radiative losses, and since the Chateauguay installation is only one layer, it has little effect on conductive losses either; in fact the main effect will be on convective losses only. Prof.Albright, of Cornell University, has built thermal curtains using Foylon XA-2425, a porous 44 x 40 count 5 oz. polyester, aluminum foil hybrid. He established that a single layer has about 50% the conductance of single strength glass. It is manufactured by the Duracote Corporation. Our own physical experiments with Foylon have not been encouraging. Prolonged exposure to water results in delamination of the foil, and extended abrasion has a similar effect. Prof.Aldrich of Pennsylvania State University has conducted tests with combinations of high thermal resistance blankets (foamed plastics) and low thermal resistance blankets (vinyl films). The results of his work have indirect bearing on this project (expensive track systems were used) but he does indicate that aluminized materials are significantly better.

Mylar coated materials have been known for some time and have been used in greenhouse environments as reflective finishes on north walls (e.g. the Brace south-facing greenhouse). Previous experience has not been encouraging as the mylar layer tends to delaminate as a result of humidity. A recent development seems to have overcome these problems. The Stauffer Chemical Company has begun to produce a mylar coated PVC reinforced film (Ultrafilm) in which the mylar is protected by a polyethylene layer. This material, developed especially for greenhouse thermal curtains, is characterized by high tear strength, resistance to humidity and ultra-violet radiation, high reflectivity on one side as well as low cost ($1.27/m^2).

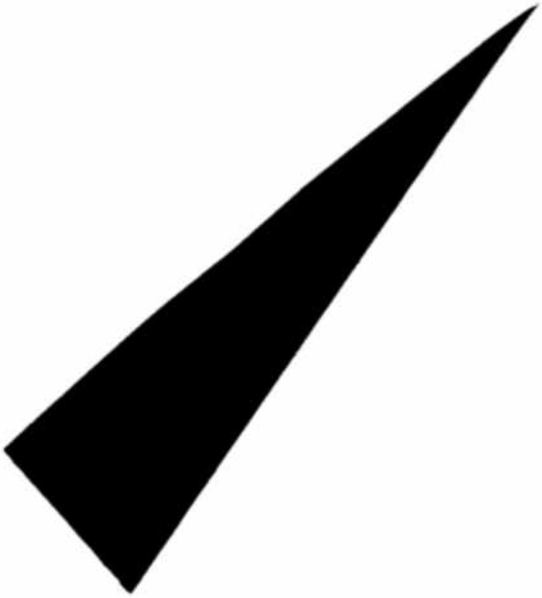


Fig.4
<u>SAMPLE OF ULTRAFILM</u>

Hardware Design

On the basis of full-scale testing a prototype system was designed which could be fabricated and installed in the existing greenhouse, and which met the criteria for a low cost retractable greenhouse insulation system.

The components for a cable suspended system are : the cable and turnbuckles, hangers which support the film, a pulley system to open and close the curtain, a method for suspending multiple layers of curtain, a puller mechanism, a horizontal joint at the leading edge of the curtain, a horizontal joint at the ground, vertical joints at the corners.

The design of these elements is based on three main criteria: thermal performance, market availability, simplicity and ease of fabrication (where fabrication is necessary) and low cost.

Cable

The suspension cable is a 12 guage plastic coated steel wire. This is capable of spanning most greenhouses (8m-12m) and is easily available. Monofilament is also used (e.g.Stuppy) but its cost ($0.23/m) is somewhat higher than steel ($0.15/m). The turnbuckles ($1.22) are a model which is particularly easy to adjust, and being cast aluminum are impervious to humidity. Spacing of the cables is 2m (see Fig.5).

Hangers

After some experimentation the most appropriate hangers were found to be common shower hooks. These have a number of advantages: low cost ($0.04), openability, resistance (naturally) to humidity. The hooks are not placed through the material, which would produce air leaks as well as rips, instead they are taped to the surface of the curtain. A 10 cm strip of 2.5 cm wide glass fibre reinforced filament tape ($.057/m) is taped through the hook and two 10 cm strips of 5 cm wide polypropylene tape ($0.038/m) are taped over the filament tape. The total cost of the tapes, per hanger, is $0.014. It is very important to note that the taping must be done to the silver (polyethylene) side of the curtain and not to the black (vinyl) side. Experiments showed that the tapes would delaminate from the vinyl over an extended period of time due to heat. No such problems were observed when taping to the polyethylene. Spacing of the hangers is 50 cm (see Fig.5).

Pulley System

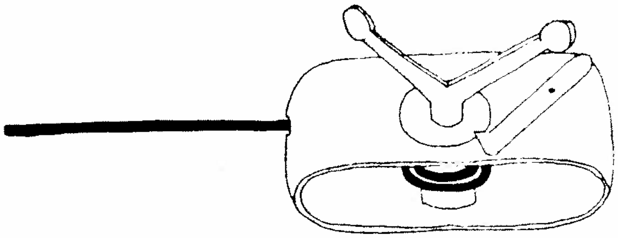
The curtain is opened and closed by means of a pulley system based on conventional practice (Simtrac, Stuppy) and using **four** marine pulleys ($3.20 each) and nylon rope ($1.00/m). These components are relatively expensive but the location of the pulley system at 4m intervals results in a typical cost of less than $1 per square metre of greenhouse (see Fig.5).

Puller Pipe

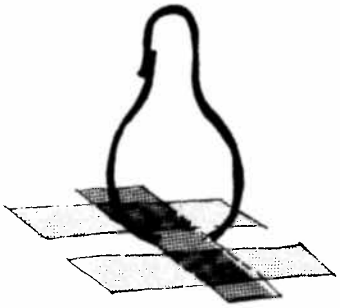
A horizontal puller pipe is suspended below the cables and pulled by the pulley system. Initial work was done using a 2.5cm dia. PVC pipe, chosen for its light weight and relatively low cost ($2.86/m). Over an extended period this pipe proved to be too flexible and had to be replaced by a similar size steel pipe ($3.10/m).

Ground Joint

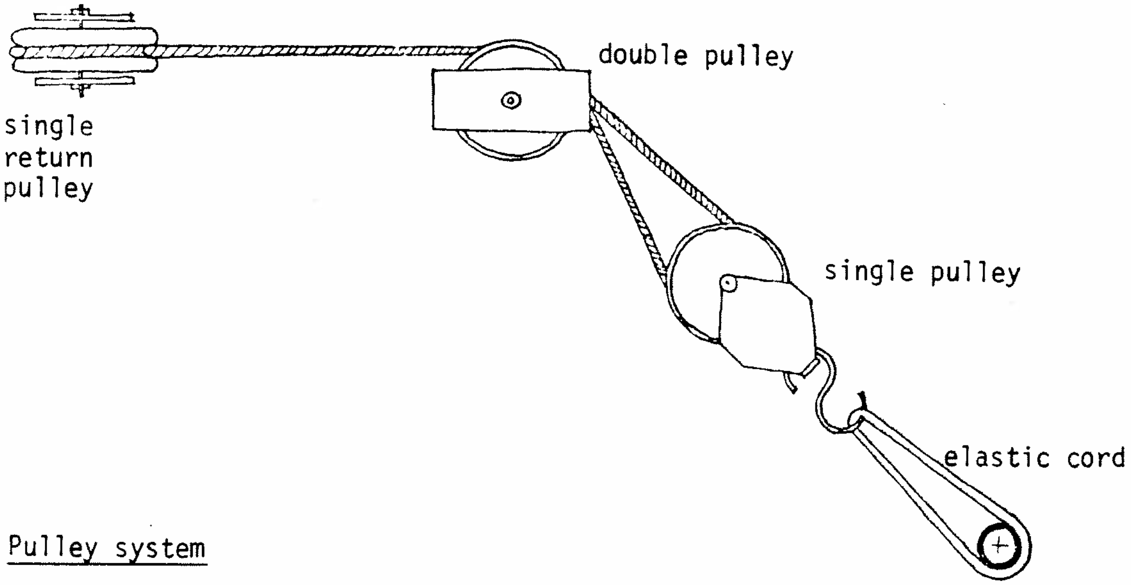
The initial design for the joint between the vertical curtain and the ground was a simple free fold, much like a window curtain. This proved to be inadequate since, in a greenhouse installation, the cold air between the curtain and the wall of the house pushes in and creates a pronounced, and awkward, billowing effect. The final detail uses a single course of concrete blocks as a low parapet and in fact a good, tight joint (see Fig.6).



Cable and turnbuckle

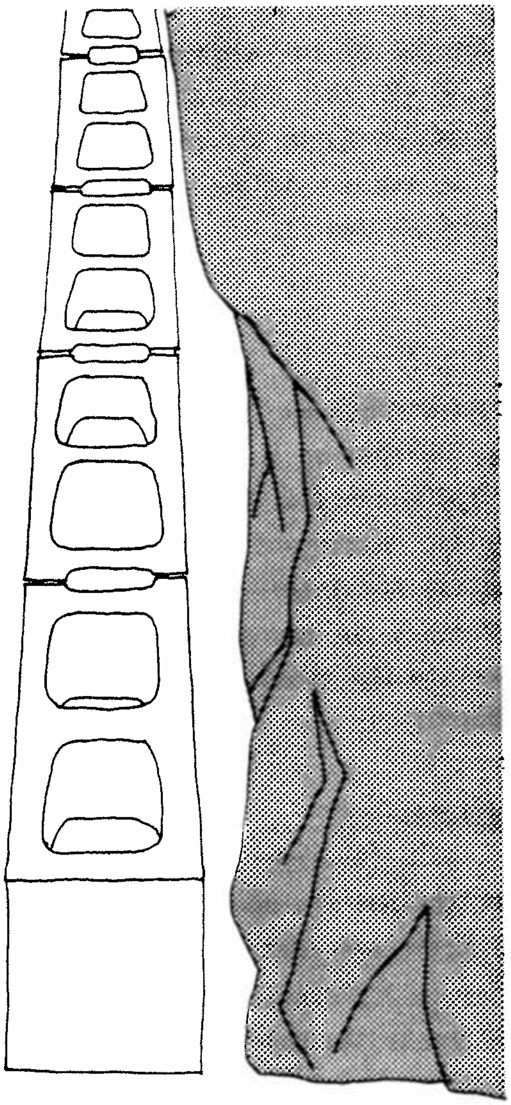


Hanger and tapes



Pulley system

Fig.5
SYSTEM DETAILS - CABLE, HANGER & PULLEY SYSTEM



The blocks are placed on the interior of the heated space to provide a low parapet against which the curtain is pushed by the cold external air mass.

Fig.6

SYSTEM DETAILS - GROUND JOINT

Leading Joint

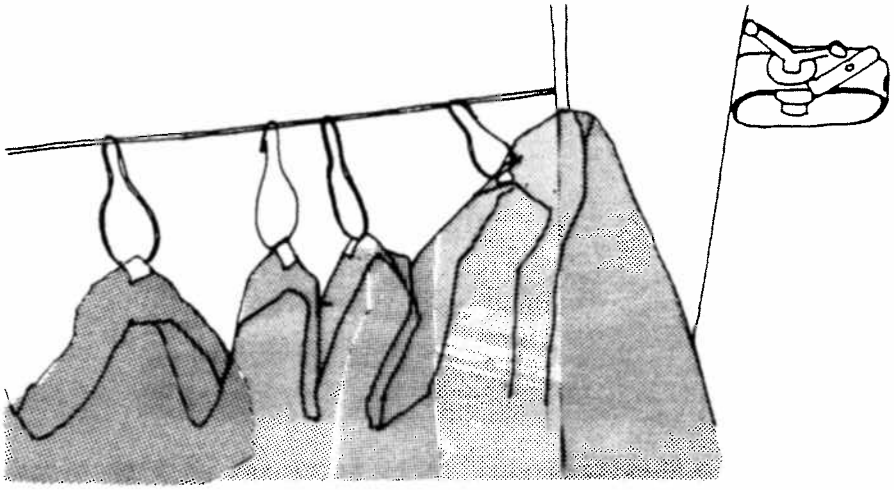
The puller pipe is pulled by the pulley system into an air tight joint that consists of two rectangular strips of foam rubber ($0.33/m) and spring clips ($0.79) that hold the pipe in place and are located at intervals of 2m. Since the pulley rope goes through the pipe and between the rubber strips, the pipe is guided directly into the joint (see Fig.7).

Vertical Joints

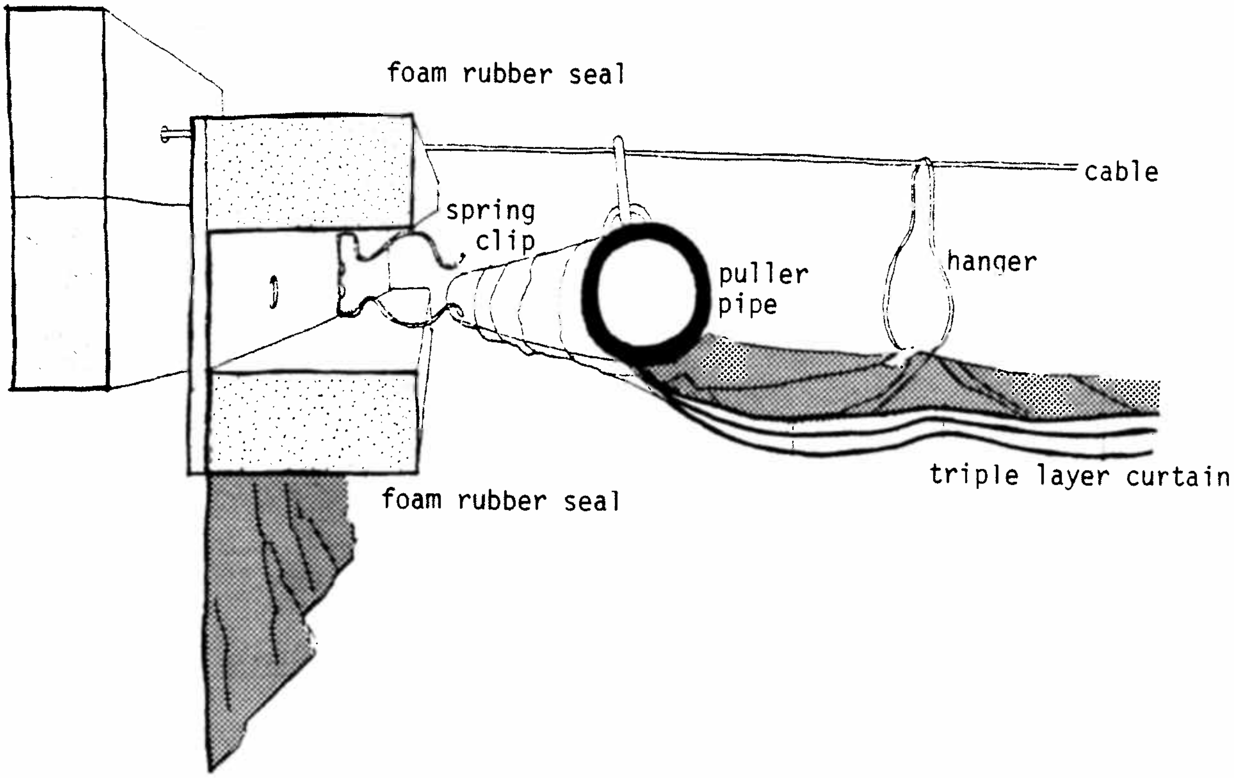
The vertical joints offer a particular problem in closure. A simple overlap is not sufficient; an automatic system is too complex and almost certainly too expensive. A compromise solution was arrived at by using a "Velcro" strip which is sealed manually. Though relatively expensive ($3.50/m) this material provides an excellent sealed joint. Moreover, the number of vertical joints is small. The strip is glued (to the vinyl side of the curtain) with Velcro adhesive No.45.

Multi-layered Curtains

The suspension of multi-layered curtains presents a particular problem. Prof.Albright has developed an ingenious solution using the plastic label fasteners that are commonly attached to price labels. This device is a small plastic cord with a "T" at each end which is attached to the material with a special hand-tool ($23.00). The fasteners ("Swiftachment", manufactured by the Dennison Manufacturing Company) come in a variety of lengths, 2.5 cm ($0.0054), 7.5 cm ($0.0045) and 12.5 cm($0.0054). Up to five layers of curtain were used in the experiments, using different combinations of fasteners (see Fig.8). The fasteners were spaced on a grid approximately 65cm x 25cm (see Fig.8). The attachment of the required number of curtain layers is done on the ground before the curtain is hung. Thanks to the special hand-tool the attachment process is extremely rapid, less than one second per fastener.A strip of filament tape was installed on the line of the fasteners before punching, to prevent tearing.



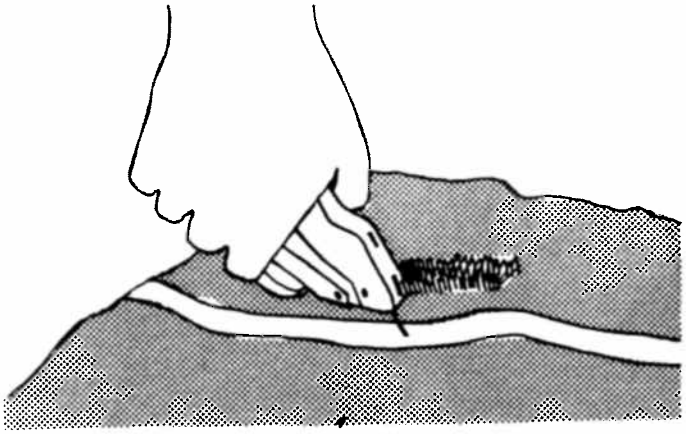
Back edge detail of curtain showing cable and turnbuckle



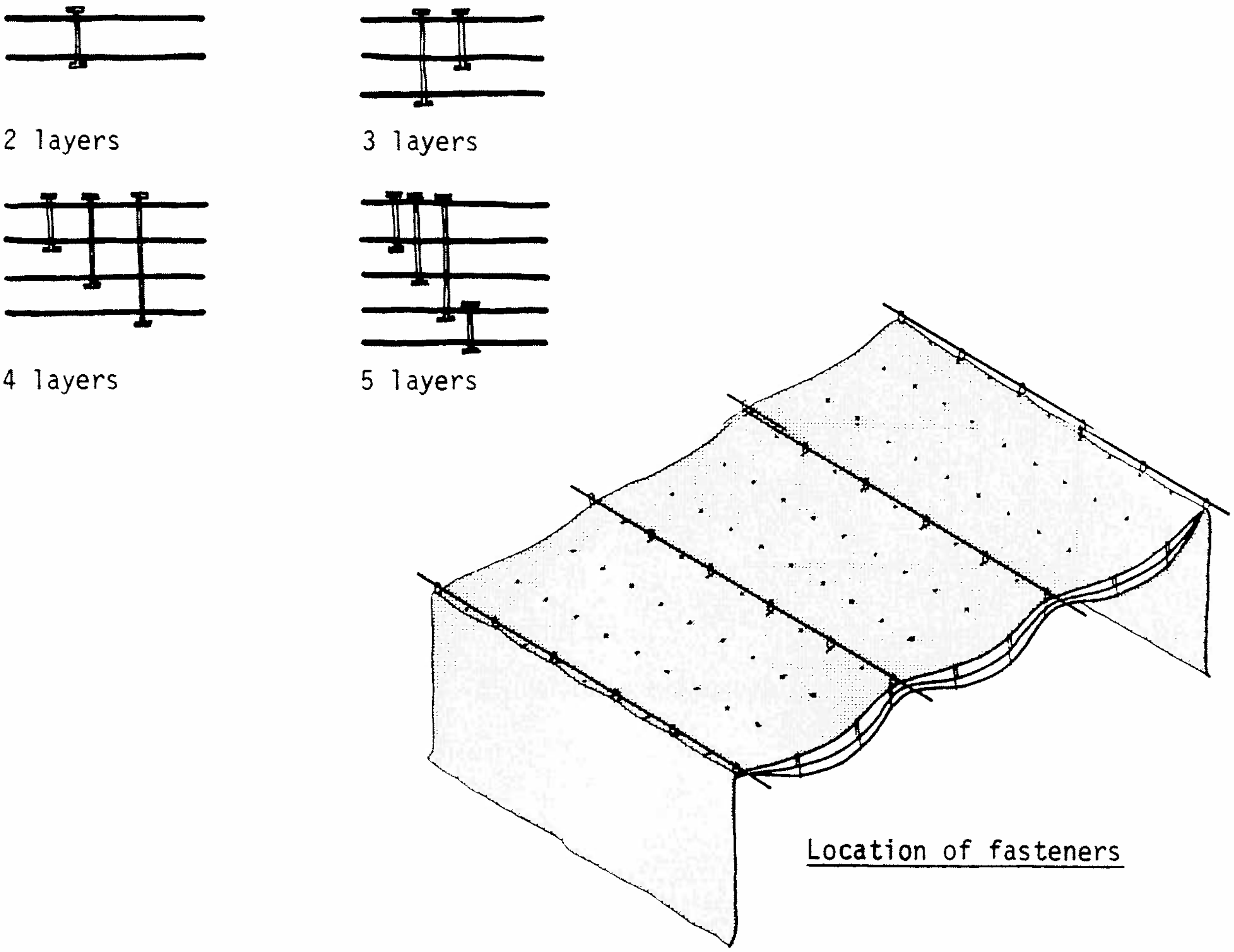
Leading edge detail

Fig.7

SYSTEM DETAILS- BACK EDGE AND LEADING EDGE DETAIL



Attaching "Swiftachment" label fasteners with hand-tool



2 layers

3 layers

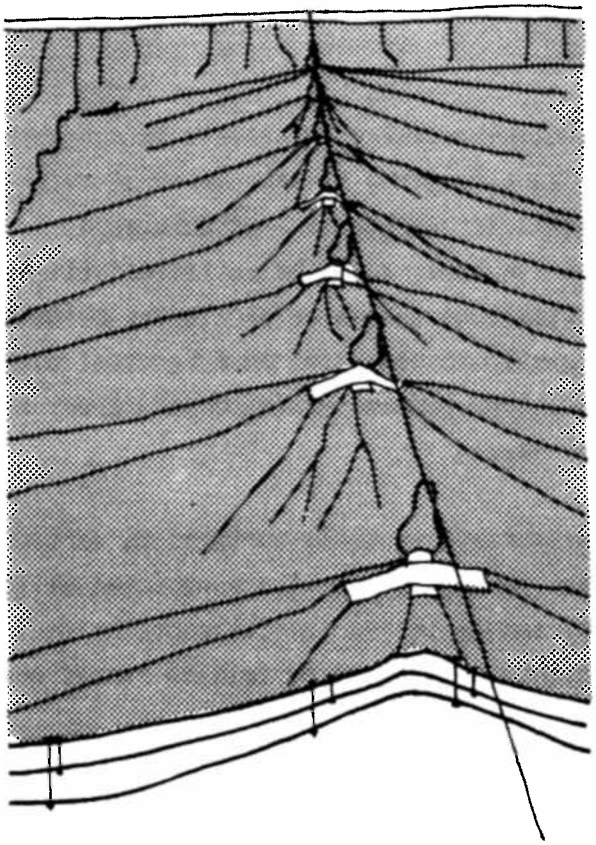
4 layers

5 layers

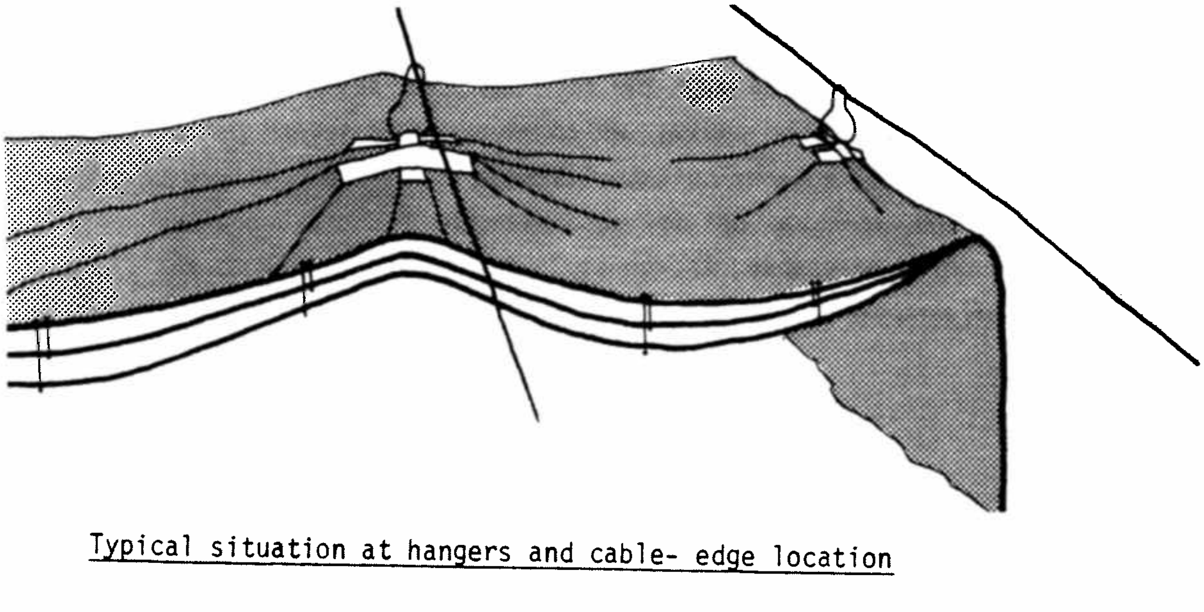
Location of fasteners

Fig.8

SYSTEM DETAILS - MULTI-LAYERED CURTAINS



Typical situation at hangers and cable- internal location



Typical situation at hangers and cable- edge location

Fig. 9

SYSTEM DETAILS - MULTI-LAYERED CURTAINS

Vertical Curtains

The vertical curtains represent a relatively lesser problem than the horizontal. In most large multi-span greenhouses they also represent less than 10% of the thermal curtain area, hence it was felt that here a single layer would be sufficient (it is otherwise extremely difficult to guarantee air layers between vertical multi-layered curtains). Condensation on a vertical curtain would simply run down to the ground and would therefore not represent a hazard for the plants.

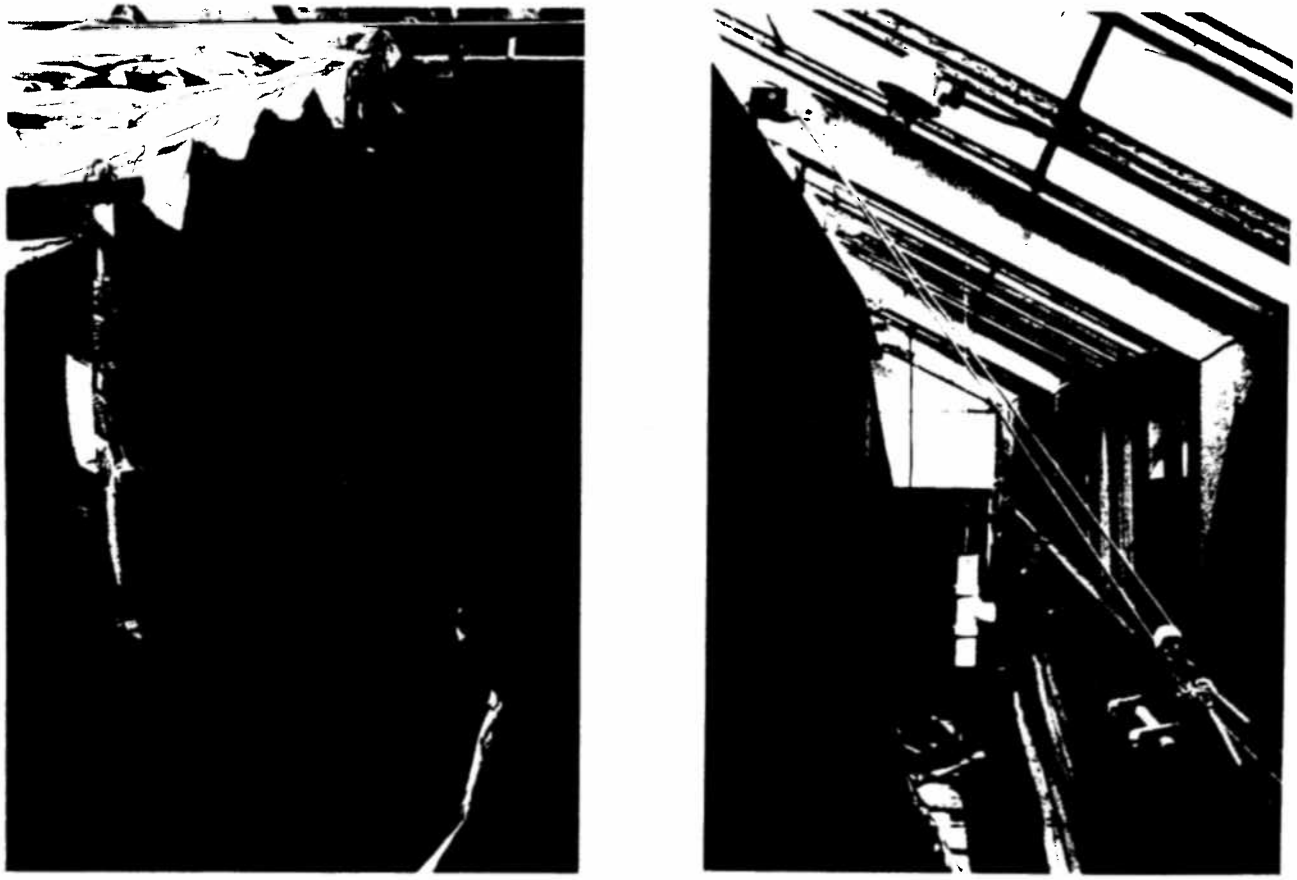
The movement system for the vertical curtains is vertical, with a fixed joint at the top, somewhat like a venetian blind, and using a similar pulley system as the horizontal curtains. This ensures a good joint, and since only 2m of curtain is stored shading is relatively minor.

The vertical curtain which is parallel to the cables is an integral part of the horizontal and opens and closes in conjunction with it (see Fig.9).

Operation

Operation of the curtain proved successful; the suspended curtain folds accordion-like on one side and does not require much space. Problems were experienced with the five layer curtain which was simply too heavy for the cables, which experienced severe deflection. The bulk of the five layer curtain likewise created problems with proper storage. This was not the case with the four layer curtain which was more manageable, though still heavy. The three layer curtain offered no problems.

Cable, hooks and puller pipe



Edge of curtain

Back edge of curtain

Fig.10

SYSTEM IN PLACE

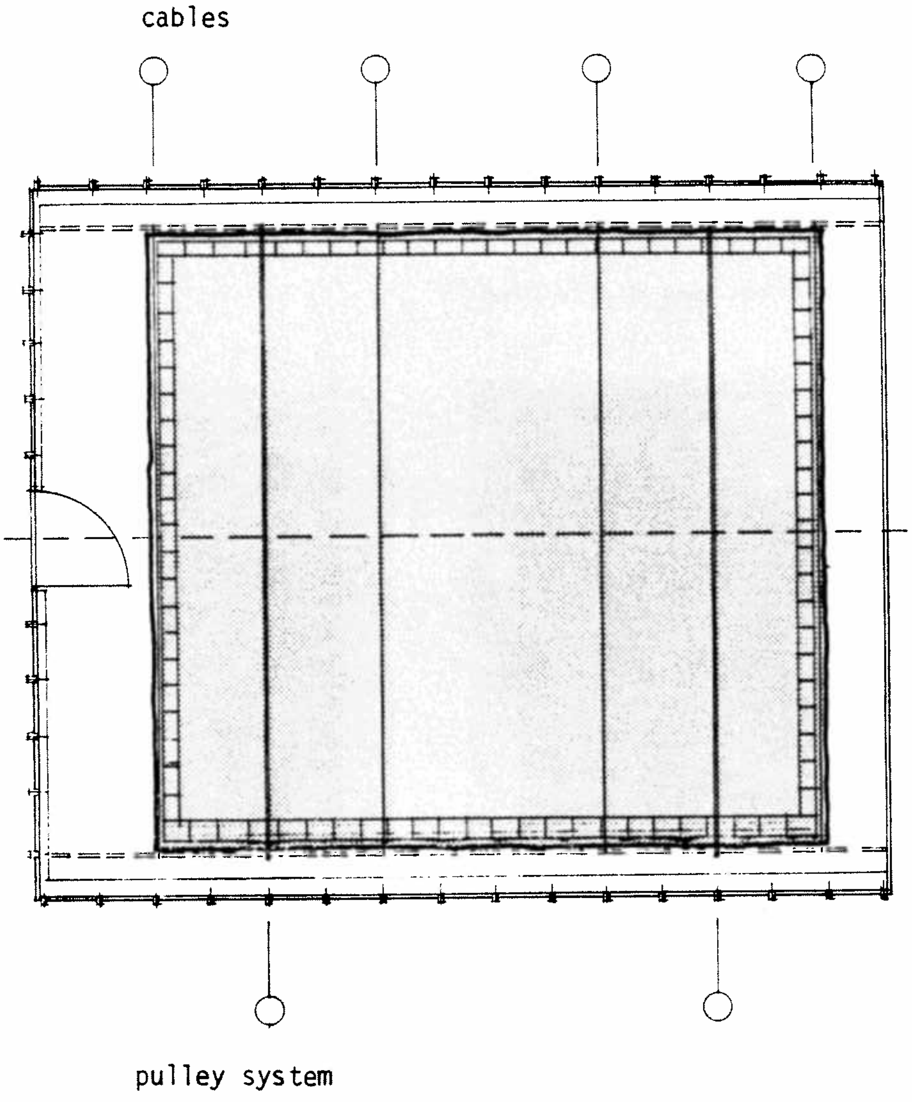
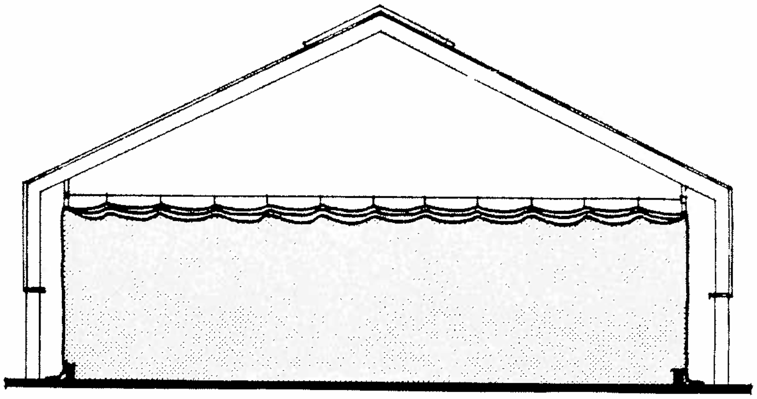
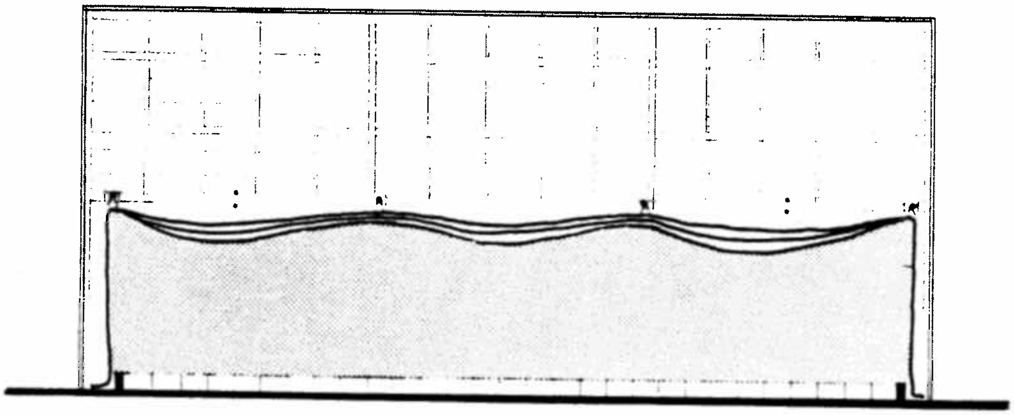


Fig.11

SYSTEM IN PLACE - PLAN



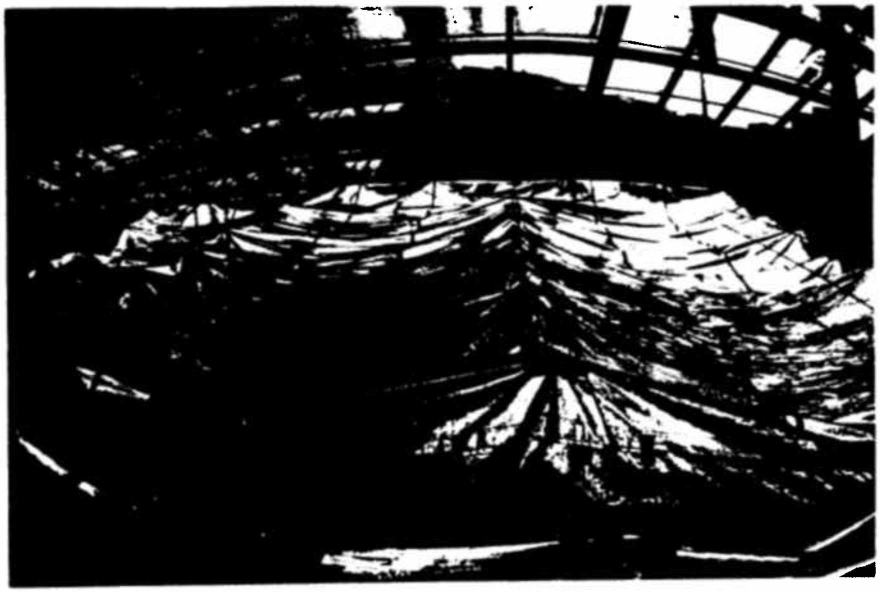
Cross section through existing greenhouse with curtain installed



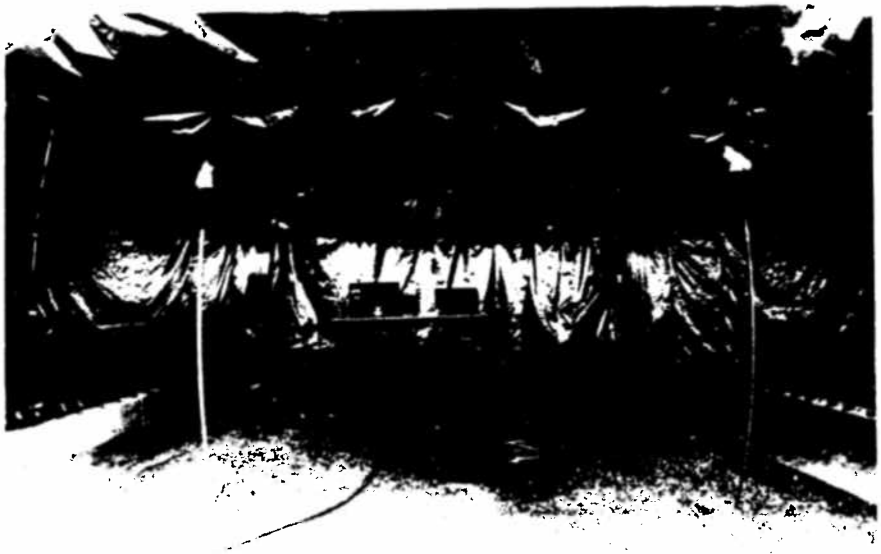
Longitudinal section through greenhouse with curtain installed

Fig.12

SYSTEM IN PLACE - SECTIONS



Exterior view above curtain



Interior view (with monitoring equipment in place)

Fig.13

SYSTEM IN PLACE

4. MONITORING THERMAL PERFORMANCE

One of the main goals of this project was to establish the overall thermal performance of the prototype thermal curtain. This implies computing conductive, convective and radiative losses. There is data available on the conductivity of various materials, and, in any case this is easily established through empirical observations. It is much more difficult to establish the convective losses. These are a direct function of the type of joints and jointing material - for which operating data are unobtainable. As a result it was necessary to adopt an empirical approach based on nightime monitoring of thermal performance of the curtain. This procedure took place from February until March, 1980 , with additional tests in May.

Monitoring Methodology

The following methodology formed the basis of the monitoring :

a. Monitor heat input (Q)

b. Monitor temperature on both sides of the curtain to establish ΔT.

c. Monitor rate of heat flow (r) through the curtain.

d. Establish the conduction losses (q)

$$q = r \times A \times \Delta T \times t$$

q = conduction losses, Watts
r = rate of heat flow, Watts/m^2-^oC
A = area of curtain, m^2
ΔT = temperature difference, ^oC
t = time, hours

e. Establish convection and radiation loss (I)

$$I = Q - q$$

I = convection and infiltration loss, Watts
Q = heat input, Watts

According to this approach both radiation and convection losses are combined and considered, for the purpose of this analysis, to be convective (or infiltration) losses.

Heat Input

The existing hot water heating system was disconnected and replaced with two 5 kWh electric fan-coil heaters. These heaters were connected to a Watt-hour meter which monitored the total amount of heat entering the greenhouse.

Temperatures

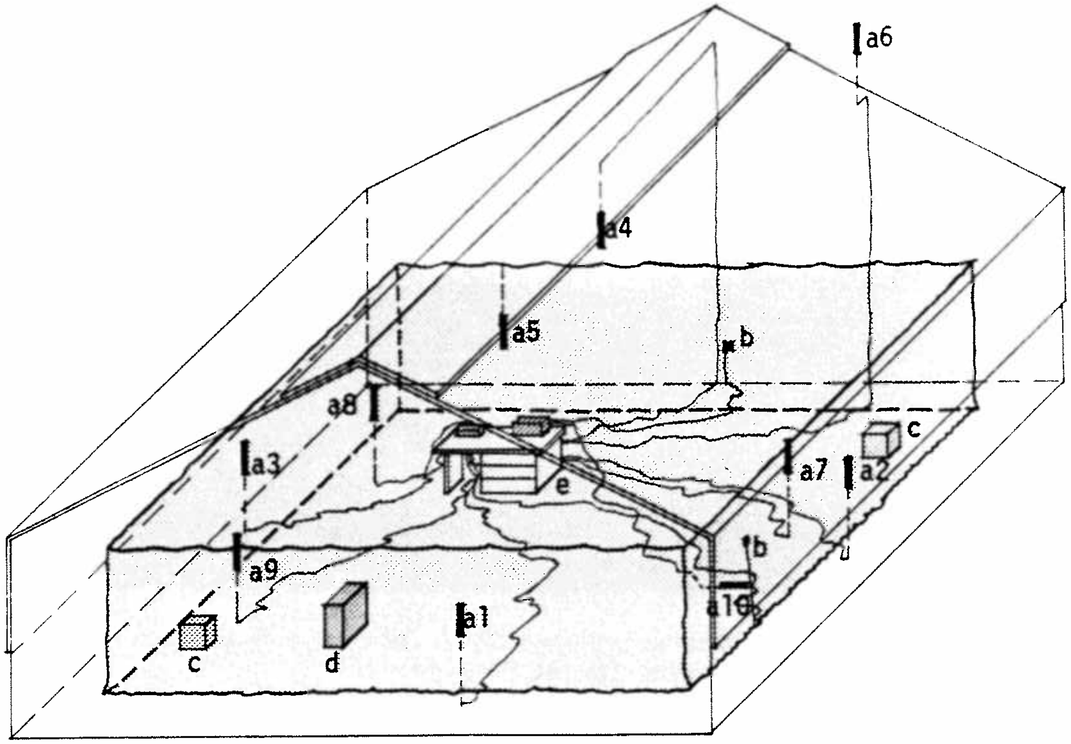
Temperatures were recorded by ten thermocouples (type TC), shrouded against radiation and convection, and linked to an Omega Model 199 DSS Digital Thermocouple Pyrometer that was equipped with a rotary switch for manual reading. Two thermocouples (4 & 5) were located at 2.7m, above the curtain in the "cold" greenhouse, and three more (1,2 & 3) at 1.2m high between the curtain and the greenhouse wall. One thermocouple (6) monitored the exterior temperature, at 3.0m height. Three thermocouples (7,8 & 9) monitored temperature at 1.2m within the "heated" greenhouse, and one (10) was imbedded in the ground. Thus temperature differences were calculated a) across the horizontal curtain, b) across the vertical curtains, and c) across the floor (see Fig.14).

Rate of Heat Flow

The rate of heat flow through the thermal curtain was measured using heat flux plates (Hy-Cal Engineering, Model B16WPJ). The heat flux plate is wafer thin and generates its own millivolt output signal which is proportional to the amount of heat flowing through the guage at that time. The heat flux plate was connected to a datalogger. One plate was permanently attached to the underside of the ceiling curtain and on-going measurements were recorded during the tests. The second heat flux plate was used to develop average figures for the vertical curtains and for the ground.

Humidity

One of the main problems associated with thermal curtains in greenhouses is condensation on the underside of the curtain, which sub-



Legend

a	Thermocouple (x10)
b	Heat flux plate (x2)
c	Electric space heater (x2)
d	Humidifier
e	Control panel

Thermocouple locations

a1, a2, a3	Between curtain and greenhouse, on sides (Height 1.20)
a4, a5	Above curtain (Height 2.70)
a6	Exterior (Height 3.00)
a7, a8, a9	Interior (Height 1.20)
a10	Interior (Underground to 0.6)

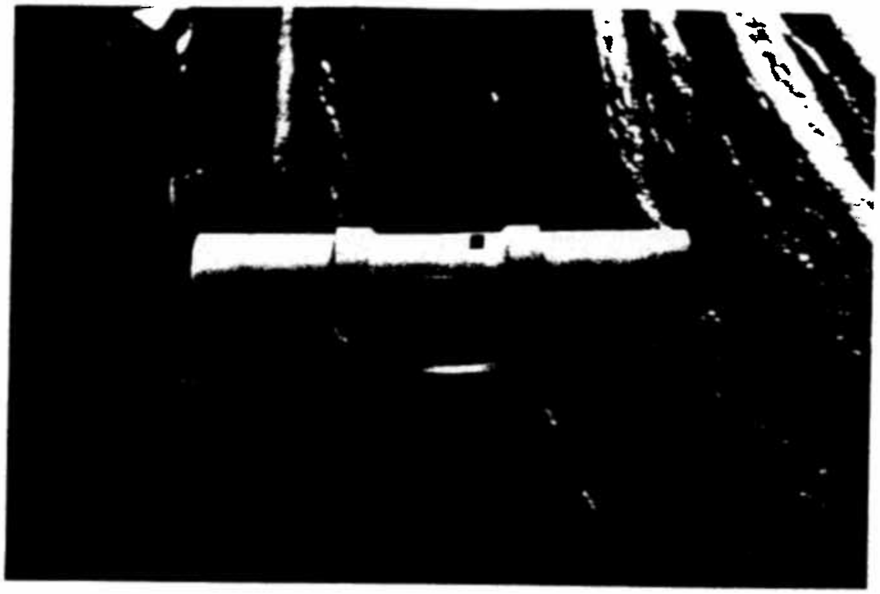
Fig.14
TEST INSTALLATION - MONITORING EQUIPMENT LOCATION

Control panel showing watt meter on left, pyrometer at centre and data logger on right.

A heat flux plate (approx 2cm x 2cm) about to be attached to the thermal curtain with a piece of masking tape.

Fig.15

MONITORING EQUIPMENT



Thermocouple shroud, fabricated from PVC pipe painted white. The thermocouple is mounted within a second smaller pipe within the horizontal pipe.

A thermocouple stand (1.2m) within the greenhouse. The concrete block parapet wall is visible at the bottom of the picture.

Fig.16

THERMOCOUPLES

sequently can cause damage to the plants. In order to observe this phenomenon, a humidity level of about 60% was maintained within the heated space using a domestic humidifier. This kind of device is not intended to simulate the humidity conditions of a greenhouse but did provide sufficient humidity for purposes of the test.

Testing Procedure

The typical test took from 1 to 3 hours and was conducted well after dusk, usually beginning between 8.00 and 9.00 pm. Temperatures were recorded manually from all the thermocouples every 10 minutes. The two heat flux plates were likewise recorded every 10 minutes, though automatically. The heaters were adjusted manually to maintain a stable temperature within the greenhouse of 18-22°C. The watt meter was read once at the beginning and once at the end of the test.

The thermal curtains were closed during the day and no attempt was made to record the cycling of temperature that would take place in a greenhouse when thermal curtains are opened and closed.

The data from the tests is included in its entirety in Appendix III.

The variable in the tests was the number of layers of thermal curtain. Three tests (4,29 & 30) were run with curtains open. Two tests (1 & 2) with a single layer, reflective side up, and four (3,5,6 & 7) with reflective side down. Six tests (8-13) were run on two layers, ten (14-17,27,28,31-34) on three layers, five tests (18-22) on four layers, and four tests (23-28) on five layers.

A summary of the test results appears on the following page.

As a result of this table it was possible to calculate a)the thermal resistances of multi-layer curtains, b) the proprtion of heat flowing through wall, floor and ceiling, and c) the proportion of heat lost by conduction and by convection.

	Chart #	Surface area horizontol curtain m²	Heat flux plate # 1 and # 2 output signals (f) mV		Conductive losses from heat flux plates #1 and #2 (q = f x c x 3.155) W		Averace rate of heat flow through the horizontal curtain W	Temperature difference between inside the curtain and in the greenhouse C°	Conductive heat losses from the horizontal curtain (q_{hori}) W	Surface area walls glazed section m²	Thermal resistance of wall curtain(R) W/m²C°	Temperature difference between inside the curtain and in the greenhouse at wall in glazed section (ΔT) C°	Conductive heat losses from wall curtain ($q_{hori\ glazed}$) = R x ΔT x A W	Surface area walls unglazed section m²	Temperature difference between inside the curtain and in the greenhouse at wall in unglazed section C°	Conductive heat losses from wall curtain ($q_{hori\ unglazed}$) = R x ΔT x A W	Surface area floor m²	Thermal resistance floor (R) W/m²C°	Temperature difference at floor (ΔT) C°	Conductive heat losses to floor (q_{floor}) = R x ΔT x A W	Duration of the experiment (t) hr.	Temperature difference between inside the curtain and out side of the greenhouse (ΔT) C°	Heat input (Q) W	Total conductive losses (q) = (q_{hori} + $q_{wall\ glazed}$ + $q_{wall\ unglazed}$ + q_{floor}) W	Convective losses (Q−qxt) = I W	Convection loss rate (I) W/m-C°
Control	4		3.53	4.59	69	94	81	15		33.6	.2664	14						1.5781			1	14	8000			
	29		3.59	3.82	70	78	74	14		33.6	.2664	12						1.5781	5		2.16	12	10900			
	30		6.76	3.97	132	81	81	14		33.6	.2664	12						1.5781	4		1.63	12	15600			
Single layer curtain reflect face in / out	1	28.8	2.63	4.19	52	86	69	17	1987	33.6	.2664	16	2018	9.6	2.5	89	28.8	1.5781	7	127	1.08	26	7000	4557	2443	4.01
	2	28.8	3.36	2.79	66	57	61	17.5	1736	33.6	.2664	17.5	2207	9.6	3	97	28.8	1.5781	4	72	1	27	7000	4132	2868	4.65
	3	28.8	3.34	2.58	65	53	59	16	1699	33.6	.2664	15	1891	9.6	2.5	83	28.8	1.5781	6	109	1	24	6000	3782	2218	4.20
	5	28.8	1.91	2.23	37	46	41	10.5	1180	33.6	.2664	9.5	1198	9.6	1.5	52	28.8	1.5781	6	109	2	17	5000	5078		-
	6	28.8	4.65	5.01	91	102	96	18.5	2764	33.6	.2664	18.5	2333	9.6	3	103	28.8	1.5781	6	109	2.16	30	12000	11466	534	.70
	7	28.8	3.25	3.51	63	72	67	13.5	1929	33.6	.2664	13.5	1702	9.6	2	75	28.8	1.5781	7	127	2	21	8000	7666	334	.35
Two layer curtain	8	28.8	2.00	2.69	39	55	47	19.5	1353	33.6	.2664	19.5	2459	9.6	2.5	108	28.8	1.5781	7	127	1	30	4500	4025	475	.69
	9	28.8	4.15	2.81	81	58	69	22.5	1987	33.6	.2664	22.5	2837	9.6	3	125	28.8	1.5781	8	145	2.16	36	15000	10929	4071	2.37
	10	28.8	2.25	2.27	44	47	46	16	1324	33.6	.2664	15	1891	9.6	2	84	28.8	1.5781	5	91	2	28	9000	6780	2220	2.10
	11	28.8	3.45	3.18	67	65	66	21	1900	33.6	.2664	21	2648	9.6	3	116	28.8	1.5781	7	127	2	35	12000	9582	2418	1.63
	12	28.8	3.63	3.11	71	64	67	20	1929	33.6	.2664	20	2522	9.6	3	111	28.8	1.5781	5	91	1	32	7500	4653	2847	4.04
	13	28.8	3.14	1.92	62	39	50	16	1440	33.6	.2664	16	2018	9.6	2.5	89	28.8	1.5781	6	109	3	24	12300	10968	1332	.79
Three layer curtain	14	28.8	1.64	1.50	32	31	32	16	921	33.6	.2664	16	2018	9.6	2.5	89	28.8	1.5781	7	127	2	22	9000	6310	2690	2.38
	15	28.8	1.38	1.32	27	27	27	15	776	33.6	.2664	15	1891	9.6	2	83	28.8	1.5781	8	145	1.75†	20	6000	5065	935	.81
	16	28.8	1.66	1.61	32	33	33	18	950	33.6	.2664	18	2270	9.6	3	100	28.8	1.5781	8	145	1.83†	26	8500	6340	2160	1.70
	17A	28.8	1.86	1.63	36	34	35	13	1008	33.6	.2664	13	1639	9.6	2	72	28.8	1.5781	9	164	.33†	23	1500	949	551	2.40
	17B	28.8	3.22*	1.31		27	27	13.5	776	33.6	.2664	13.5	1702	9.6	2	75	28.8	1.5781	9	164	1.5	21	6300	4075	2225	3.12
	27	28.8	.50*	.48*				7.5	420	33.6	.2664	7.5	935	9.6	1	42	28.8	1.5781	6	109	1.5	10	3300	2287	1013	2.55
	28	28.8	.22*	.30*				10.5	588	33.6	.2664	10.5	1324	9.6	1.5	58	28.8	1.5781	8	145	1.56†	16	2600	3340		-
	31	28.8	.88*	1.32*				10	560	33.6	.2664	10	1251	9.6	1.5	56	28.8	1.5781	3	54	.66†	15	1800	1272	528	1.98
	32	28.8	1.74*	1.15*				8	448	33.6	.2664	8	1009	9.6	1	45	28.8	1.5781	4	72	.83	15	2400	1576	824	3.50
	33	28.8	2.53*	2.24*				10.5	588	33.6	.2664	10.5	1324	9.6	1.5	58	28.8	1.5781	5	100	.83	17	2200	1781	482	1.57
	34	28.8	1.03*	1.18*				13	728	33.6	.2664	13	1639	9.6	2	72	28.8	1.5781	8	145	2	19	7800	5168	2632	2.87
Four layer curtain	18	28.8	1.79	1.35	35	28	31	16.5	927	33.6	.2664	16.5	2081	9.6	2.5	92	28.8	1.5781	4	72	2	24	8500	6344	2156	1.86
	19	28.8	1.93	1.85	38	38	38	19.5	1094	33.6	.2664	19.5	2459	9.6	2.5	108	28.8	1.5781	5	91	2	28	10800	7504	3296	2.40
	20	28.8	1.58	1.56	31	32	32	18.5	921	33.6	.2664	18.5	2333	9.6	2.5	103	28.8	1.5781	8	145	2	27	8000	7004	1000	.75
	21	28.8	1.29	1.50	25	30	27	15.5	777	33.6	.2664	15.5	1955	9.6	2	96	28.8	1.5781	6	109	2	24	5000	5834		-
	22A	28.8	1.72	1.44	34	30	32	16.5	921	33.6	.2664	16.5	2081	9.6	2.5	92	28.8	1.5781	6	109	1	21	5000	3352	1643	2.89
	22B	28.8	1.64	1.48	32	30	31	17.5	892	33.6	.2664	17.5	2207	9.6	2.5	97	28.8	1.5781	7	127	1	23	4200	3323	877	1.42
Five layer curtain	23	28.8	1.13	1.14	22	23	23	12.5	662	33.6	.2664	11.5	1450	9.6	2	64	28.8	1.5781	9	145	1	22	2000	2321		-
	24	28.8	1.04	.97	20	20	20	11.5	576	33.6	.2664	11.5	1450	9.6	2	64	28.8	1.5781	6	109	2	17	5100	4398	702	.86
	25	28.8	.89	1.17	17	24	20	11.5	576	33.6	.2664	11.5	1450	9.6	2	64	28.8	1.5781	6	109	2.33	14	5100	5009	100	.10
	26	28.8	.36*	1.57*				8	460	33.6	.2664	8	1009	9.6	1	45	28.8	1.5781	4	72	2.16	12	5300	3407	1893	3.11

* Refer to Appendix III, Monitoring Data, for location of heat flux plates.

Summary of Experimental Results

The table on page 31 presents a summary of the experimental results of the 34 tests.

The data is organized according to a) losses through horizontal curtain, b) losses through east, west and south (glazed in greenhouse) walls, c) losses through north (unglazed in greenhouse)wall and d) losses to ground. The losses (conduction) to ground and through the walls are computed by establishing a thermal resistance and temperature difference experimentally, and computing the heat loss with the formula:

$$R \times \Delta T \times A = q$$

R = thermal resistance, Watts/m^2-^oC

ΔT = temperature difference, ^oC

A = surface area, m^2

q = heat loss(conduction), Watts

The losses(conductive) through the horizontal curtain were measured directly using the heat flux plate. The first heat flux plate column lists the direct readings in millivolts, the second column lists the actual heat loss in Watts, following the formula:

$$f \times c \times 3.155 = q$$

f = heat flux plate output signal, millivolts

c = calibration factor

q = heat loss(conduction), Watts

The final column lists an average 'q' for conductive heat loss through the curtain.

The convective (including radiative) losses are computed according to the formula:

$$Q - \left[(q_{ceiling} \times t) + (q_{walls} \times t) + (q_{ground} \times t) \right] = I$$

Q = heat input, Watts

q = heat loss(conductive), Watts

t = time, hours

I = convection loss, Watts

Thermal Resistance

From the results established experimentally it is possible to compute the thermal resistance (RSI) of various multi-layered curtains using the formula:

$$R = \frac{q}{A \times \Delta T}$$

R = thermal resistance, Watts/m^2-^oC
q = conductive heat loss, Watts
A = surface area, m^2
ΔT = temperature difference, ^oC

The average thermal resistance of the curtain was calculated with the following results:

One layer (reflective up)	0.268	Watts/m^2-^oC
One layer (reflective down)	0.259	
Two layers	0.557	
Three layers	0.760	
Four layers	0.829	
Five layers	0.905	

In the 2,3,4 and 5 layer configurations, the topmost layer was always installed reflective side up, and the rest reflective side down.

Convection Loss Rate

From the total convective losses (I) established experimentally it is likewise possible to compute the convective loss per metre of joint. In order to do this two assumptions were made. First, radiation losses were ignored and included into the convective losses. Second, lacking any experimental evidence as to the different efficiency of the joints, it was assumed that all joints performed equally. This is certainly not true, and future work will have to be done to determine the differences in performance.

The convection loss rates were calculated for each experiment and appear as 'i' in the last column, the following formula was used:

$$i = \frac{I}{35.2 \times \Delta T \times t}$$

i = convection loss rate, Watts/m-^{o}C
I = convection loss, Watts
ΔT = temperature difference, ^{o}C
t = time, hours

The total length of joints in the test installation was 35.2m. This includes the floor joint, the four vertical joints, the puller pipe joint, but not the fixed back edge joint or the integral joint between the walss and ceiling. As a result of these calculations the average convection rate was found to be 2.13 Watts/m-^{o}C.

5. ECONOMICS OF THERMAL CURTAINS

The test installation, although not done at a full commercial scale, has permitted the development of data as to both the thermal performance of the curtain, and its cost. However, in order to evaluate the economic performance it is necessary to look at a much larger greenhouse where the ratio between edge conditions and surface area is more representative. This exercise involves a) calculating the heat loss of a large multi-span greenhouse, b) designing a thermal curtain for the greenhouse, c)calculating the heat loss of the greenhouse with thermal curtain, d) using the cost of the curtain and the value of the energy savings evaluate the economic performance using life cycle costs.

The Greenhouse

The greenhouse consists of three bays (10.5m wide), 61m long. The construction is good quality, single layer glass (RSI 0.2025) and reasonably air tight (1 air change/hour). The total area of the greenhouse is 1921.5 m^2. The heat loss rate is as follows:

	Area,m^2	RSI,Watts/m^2-^oC	Watts/^oC
Roof	2013.0	0.2025	9940
Walls	618.0	0.2025	3051
Floor	1921.5	1.5781	1217
Infiltration	5947 m^3		1987
Total			16,195 Watts/^oC

The Thermal Curtain

The thermal curtain is a three later cable suspended type, with single layer curtains on the walls. The thermal resistance of the three layer curtain is 0.760, and of the single curtain is 0.268. The infiltration rate is 2.13 Watts/m-^oC of curtain joint; there are 423.5 m of joints. The cables are at the 3m height.

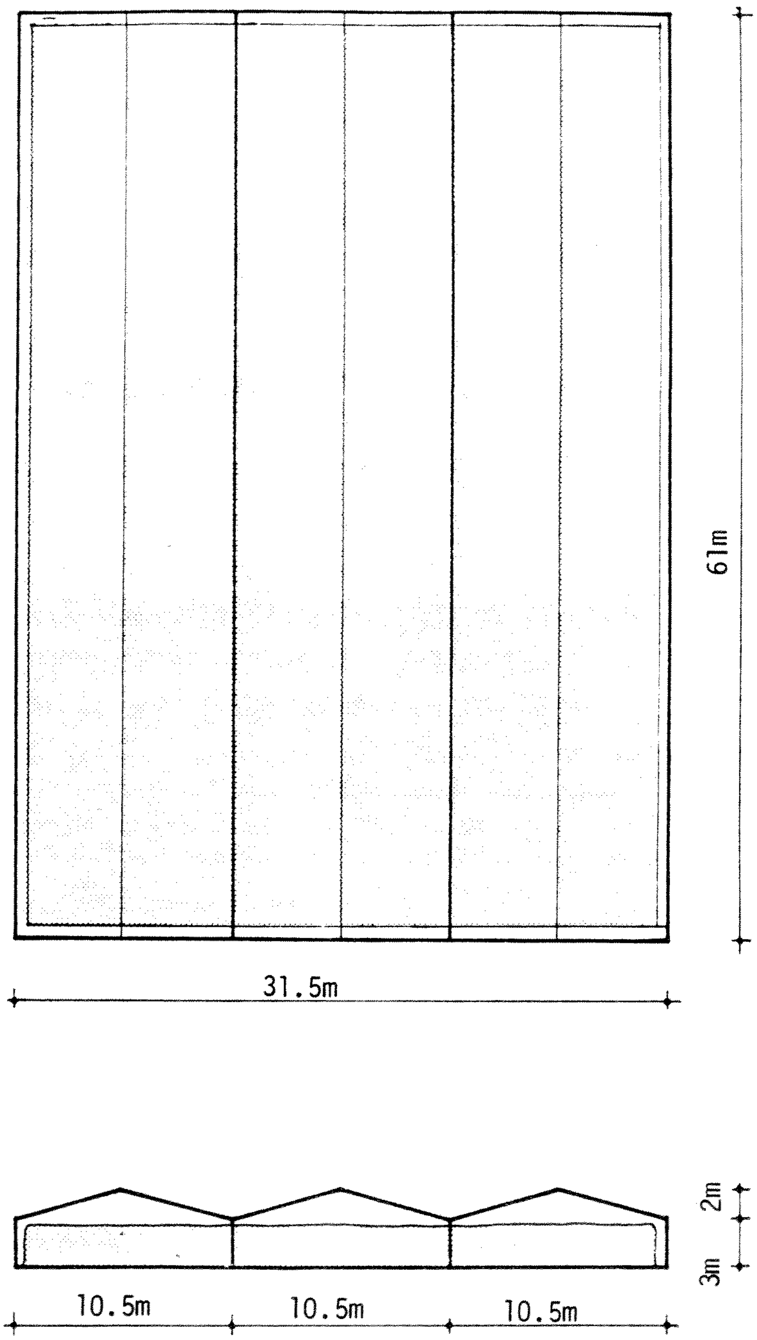


Fig.17

GREENHOUSE USED IN ECONOMIC ANALYSIS

The heat loss rate is as follows:

	Area,m^2	RSI,W/m^2-^oC	Watts/^oC
Roof	1921.5	0.7609	2525
Walls	555.0	0.2687	2065
Floor	1921.5	1.5781	1217
Infiltration	423.5m x 2.13 W/m		902
Total			6,709 Watts/^oC

Annual Heating Costs

The following assumptions are made in computing the annual heating costs: fuel cost is 2.5 ¢/kWh, the nightime heating period is 16 hours, the nightime degree days (or degree nights) are 4114 (Montreal region). Using these figures the annual nightime heating cost of the greenhouse is $26,642, while the annual nightime heating cost of the greenhouse with the thermal curtain is $11,025. The annual saving is $15,617.

Thermal Curtain Costs

The detailed costs of the thermal curtain are as follows:

a. Drive mechanism	$ 500.00
b. Concrete blocks	255.75
c. Puller pipes	567.30
d. Pulley systems	537.60
e. Cables	164.61
f. Turnbuckles	113.46
g. Lumber	109.80
h. Hangers	79.84
i. Nylon rope	1260.00
j. Velcro tape	84.00
k. Ultrafilm material	7580.00
l. Foam rubber	120.78

m. Pipe clips	73.47
n. Contact cement	20.95
o. Elastic cord	45.00
p. Fasteners	236.25
q. Tapes	473.70
r. Labour cost ($1.50/m^2)	2882.25
TOTAL COST	$ 15,104.76
TOTAL UNIT COST	$ 7.86/m^2

Payback Period

The simple payback period can be computed by dividing the Capital Investment by the Present Day Annual Savings.

$$\text{Simple Payback} = \frac{15{,}105.}{15{,}617.} = 0.96 \text{ years}$$

Thr true payback period, which takes into account escalation rate (10%) and discount rate (12%) is slightly more than one year.

This meets a very important criteria for the commercial greenhouse grower who requires an extremely short payback period for his investment. Most growers are rather small businesses with the minimal investment in physical plant (a wood and plastic greenhouse may cost as little as $35/m^2) and little capital to invest. A thermal curtain, no matter how efficient, will not find widespread application if the pay back period is too long.

Life Cycle Costing

It is useful to calculate the life cycle costs in order to be able to compare annual energy savings and capital outlay. Furthermore, there are cyclical renewal costs to be taken into account. It has been assumed that the life of the hardware of the thermal curtain system (motor, pulleys, cables) can be expected to be 15 years. It is expected that the curtain material (including hangers, fasteners and tapes) will require replacement during that time, and renewal of these components has been assumed to happen every five years.

j. Velcro tape	$ 84.00
k. Ultrafilm material	7580.00
h. Hangers	79.84
p. Fasteners	236.25
q. Tapes	473.70
r. Labour cost ($0.75/m^2)	1440.75
TOTAL RENEWAL COST	$ 9894.54

The life cycle cost analysis assumes a 15 year period of study, a 12% discount rate, a 10% escalation rate for energy costs, and a 8% escalation rate for renewal costs. The Total Present Value of nightime operation of the greenhouse with and without a thermal curtain has been computed and the result shows the definite advantage of the thermal curtain (see pps.40-41).

TPV (without thermal curtains)	$ 347,038.
TPV (with thermal curtains)	$ 173,845.

Option: Without thermal curtain

Discount Rate: 12 %; Period of Study: 15 yrs; Base Year: 19 80 (Year 0)
Enter inflation rates below for each cost category

Cost Category				PV Factor	Present Value
1. Capital Costs (Escalation __ %)	Qty	Unit Rate	Est. Cost 19__ $	SPF	
A					
B					
C					
D					
E					

Total Present Value - Capital Costs: $

2. Operations & Maintenance (Escalation __ %)	Qty	Unit Rate	Est. Annual Cost 19__ $	Years	CSPF	
A						
B						
C						
D						
E						

Total Present Value - Operations & Maintenance: $

3. Energy	Escal. Rate	Consumption	Unit Rate	Est. Annual Cost 19 80 $	Years	CSPF	
A Electricity	%						
B Gas	10 %	1,065 kWh	2.5¢	26,642.	15	13.026	347,038.
C Oil	%						
D	%						

Total Present Value - Energy: $347,038.

4. Cyclical Renewal (Escalation __ %)	Qty	Unit Rate	Est. Cost 19__ $	Year	SPF	
A						
B						
C						
D						
E						

Total Present Value - Cyclical Renewal: $

5. Salvage/Residuals (Escalation __ %)	Est. Cost 19__ $	Year	SPF or SPV	
A				
B				

Total Present Value - Salvage: $

TOTAL PRESENT VALUE - Option # __ (1+2+3+4-5) : $347,038.

Option: With Thermal Curtain

Discount Rate: 12 %; Period of Study: 15 yrs; Base Year: 1980 (Year 0)
Enter inflation rates below for each cost category

Cost Category				PV Factor	Present Value
1. Capital Costs (Escalation __%)	Qty	Unit Rate	Est. Cost 1980 $	SPF	
A Curtain	-	-	15,105.	-	15,105.
B					
C					
D					
E					
Total Present Value - Capital Costs:					$ 15,105.

2. Operations & Maintenance (Escalation __%)	Qty	Unit Rate	Est. Annual Cost 19__ $	Years	CSPF	
A						
B						
C						
D						
E						
Total Present Value - Operations & Maintenance:						$

3. Energy	Escal. Rate	Consumption	Unit Rate	Est. Annual Cost 1980 $	Years	CSPF	
A Electricity	%						
B Gas	10 %	441 kWh	2.5 ¢	11,025.	15	13.026	143,611.
C Oil	%						
D	%						
Total Present Value - Energy:							$ 143,611.

4. Cyclical Renewal (Escalation 8 %)	Qty	Unit Rate	Est. Cost 19__ $	Year	SPF	
A + 5			9,895.	1985	0.834	8,252.
B + 10			9,895.	1990	0.695	6,877.
C						
D						
E						
Total Present Value - Cyclical Renewal:						$ 15,129.

5. Salvage/Residuals (Escalation __%)	Est. Cost 19__ $	Year	SPF or SPV	
A				
B				
Total Present Value - Salvage:				$

TOTAL PRESENT VALUE - Option # __ (1+2+3+4-5) :	$ 173,845.

6. CONCLUSIONS

a. Costs

One of the main criteria has been to develop a thermal curtain system which is low cost. The analysis of economic performance described in Section 5 indicates that this can be achieved. The thermal curtain pays for itself in approximately one year in energy savings, and life cycle costing has established that it is beneficial over a fifteen year cycle, even assuming a relatively short life (5 years) for the curtain material itself. This type of curtain will be particularly attractive to the small producer who cannot invest large amounts in capital equipment, and who requires a short pay back on his investment. One would assume that better capitalized (larger) growers could afford a more expensive retractable insulation system with a longer pay back period, than the $7/m^2 cost of the low cost system.

b. Thermal Resistance

The experimental data described in Section 4 gives the thermal resistances of one to five layer thermal curtains. Empirical observations show that four and five layer curtains are both too heavy and too bulky for practical operation. It is most likely that four and five layer curtains could be used, but only with more expensive track systems, which would not deflect with the greater load. Although theoretically the thermal resistance of multi-layered curtains should increase in direct proportion to the number of layers, experimental data does not bear this out. Fig.18 shows a flattening of the curve after three layers. This may be due to reduced thermal efficiency as the cables deflect and more cold bridges are created by touching layers, though this is not certain.

One of the unknowns in thermal curtains is infiltration or convection loss. Since there are no standards for the performance of thermal curtains it is difficult to say if the 12% infiltration loss of the curtain (in the multi-span example, see Section 5) is good or bad. Interestingly it is the same proportion of overall

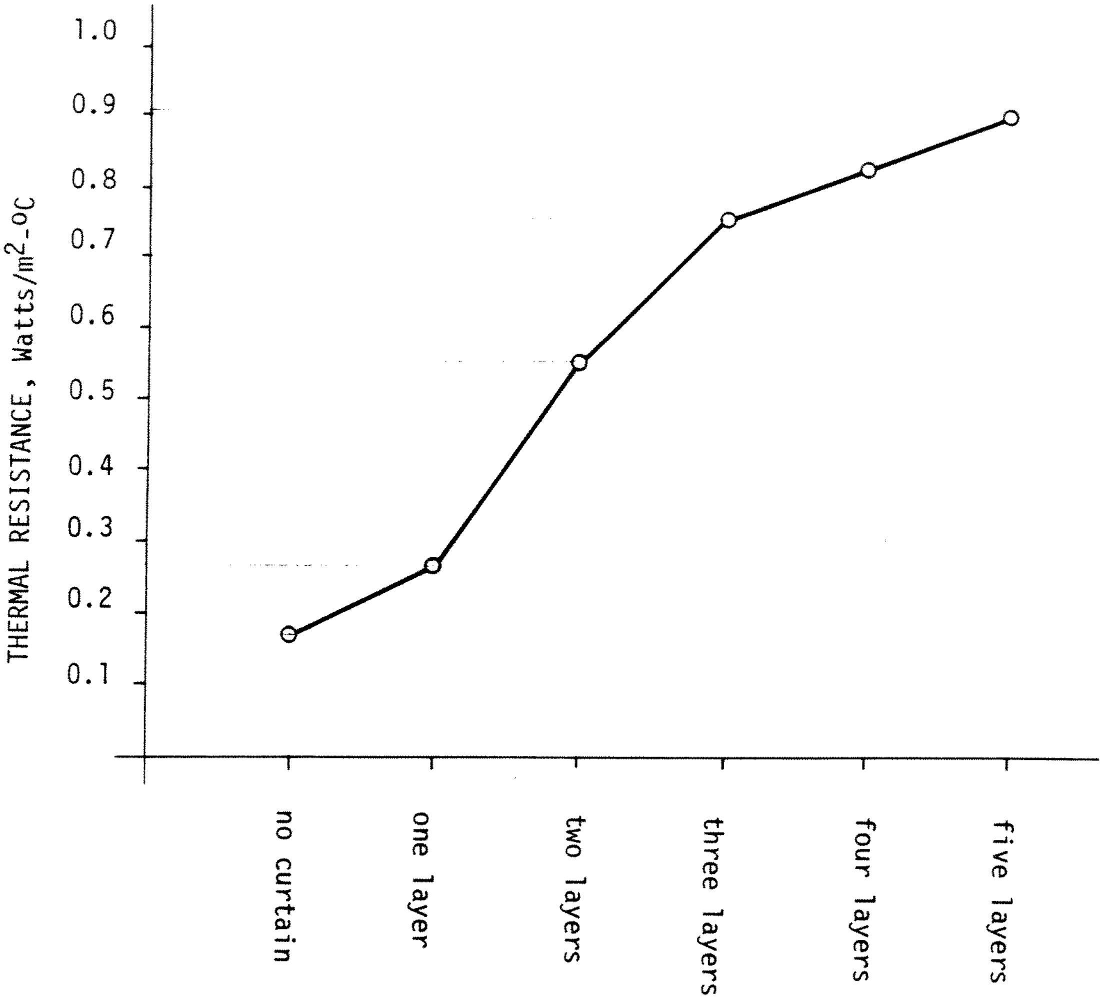


Fig. 18

THE THERMAL RESISTANCE OF A GREENHOUSE WITH AND WITHOUT THERMAL CURTAINS heat loss as in the uninsulated greenhouse.

c. Fabrication

The operation of the multi-layered thermal curtains proved to be acceptable, with the already mentioned limitation on four and five layered installations. Up to three layers the curtain opened and closed smoothly and stored neatly in a relatively small volume.

The installation of thermal curtains takes place in two steps: the off-site fabrication of the curtain, and the on-site installation of supporting cables and hanging of the curtain. The second step does not present any major problems. A number of requirements must be satisfied by the greenhouse in order to install any retractable insulation system: the heating elements must not be located outside the insulated area, there must not be too many vertical obstructions (structural posts, controls, etc.), and the shape of the greenhouse should be more or less regular. Certain greenhouses, particularly older models, may require extensive modification before a thermal curtain could be installed.

The off-site fabrication of the cable supported curtain is relatively laborious. First of all, all mylar type materials (including Ultrafilm) come in narrow rolls, usually 1.8m wide. This implies extensive taping to produce the large surfaces required. So far this step is unavoidable, though it might be accelerated by using glues (2% VCMH resin dissolved in 98% cyclohexynol). The cable supported system also requires two additional steps: fixing the hangers to the topmost layer, and attaching the layers together with Swiftachment fasteners. Both of these steps are time consuming.

It was with a view to simplifying fabrication that a multi-cable system was investigated (see Appendix II) following the completion of thermal monitoring of the cable supported systems. The multi-cable system simplified fabrication dramatically, though cost increased about 20%. It was not possible to evaluate the thermal performance of the multi-cable option, but if it proves to be comparable to the cable supported type systems it may turn out to be an interesting solution.

d. Operation

One of the questions frequently asked about thermal curtains concerns problems associated with condensation. Serious condensation was observed to occur on the underside of a single layer curtain. When the installation was increased to two or more layers no condensation problems occured. No condensation was observed in the sealed air spaces. The single layered vertical curtains have extensive condensation, but this does not present any problems as it runs down the curtain surface to the ground.

No delamination of the tapes was observed during the tests, whether due to heat or to mechanical stress. A more extensive materials test would have to be carried out to ascertain the life of taped joints (though 5 years is all that would be required), particularly as the matrix (Ultrafilm) is a new material.

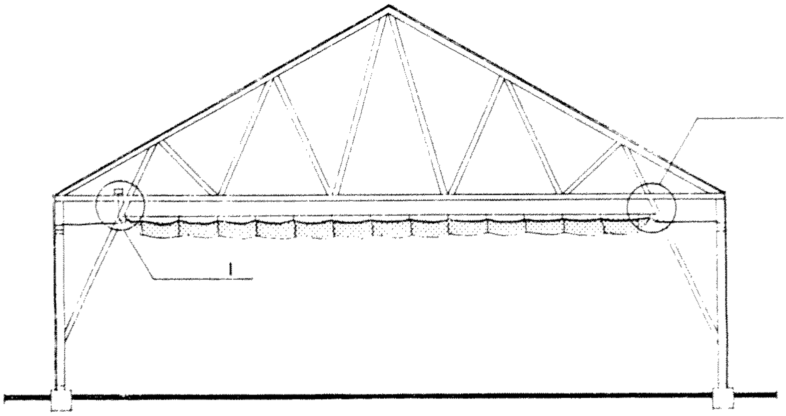
APPENDIX I

CABLE SUPPORTED OPTION

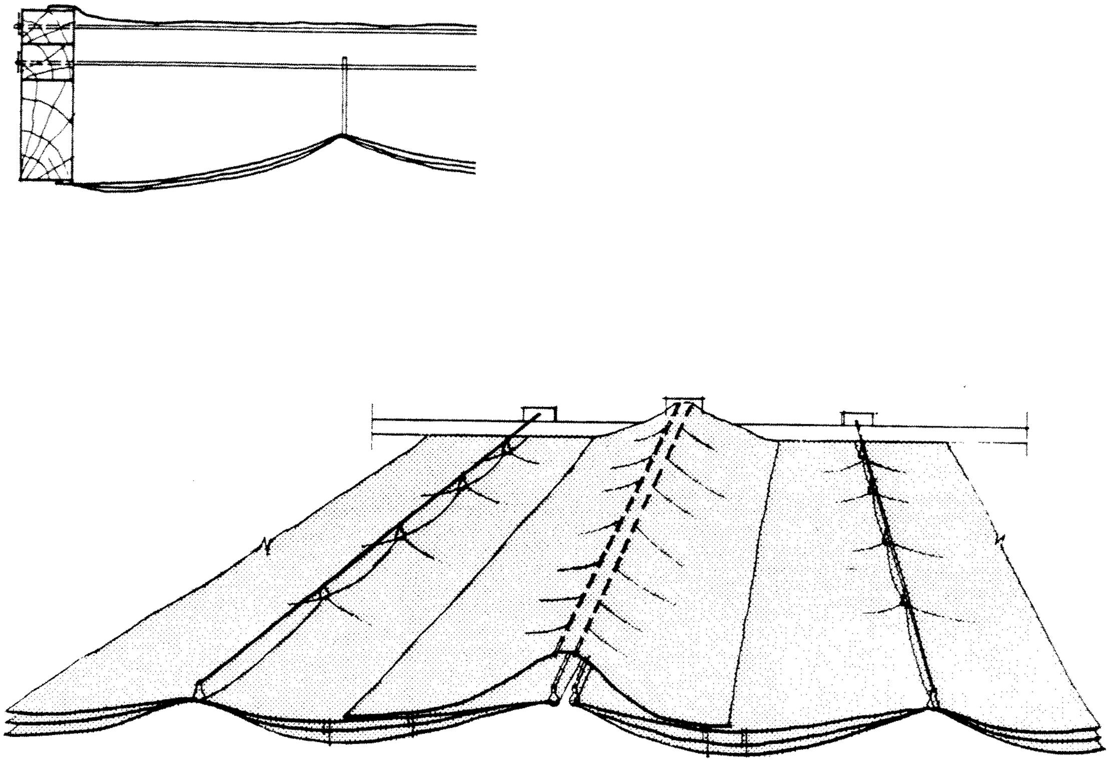
An analysis of the thermal curtain was made by designing the system for a specific greenhouse, in this case a wood & plastic greenhouse on the outskirts of Montreal measuring 61m long and 10.5m wide. Only a horizontal curtain was considered. The following costs were established:

Cables, hangers, turnbuckles tapes	$ 253.94
Curtain material (3 layers) & fasteners	2378.87
Pulley system & motor drive	1204.20
Puller pipes & lead joint	332.31
Labour ($1.40/m^2)	896.70
TOTAL COST	$ 5066.02
TOTAL UNIT COST	$ 7.92/m^2

This particular installation does not permit the curtain to travel to the eaves but only to the diagonal struts. A fixed baffle shields the gap.



Cross section through greenhouse



Detail of lapping joint between two sections of multi-layer curtain

Fig.19

LAP JOINT

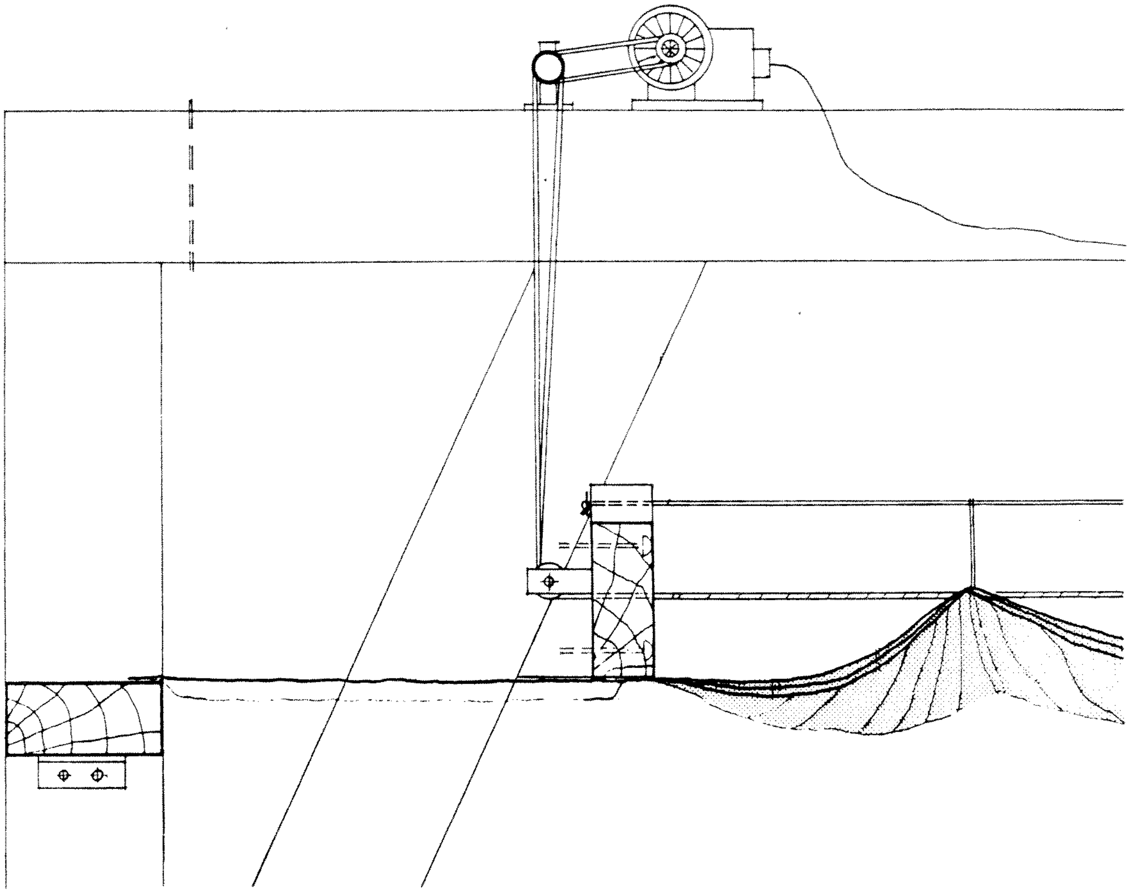
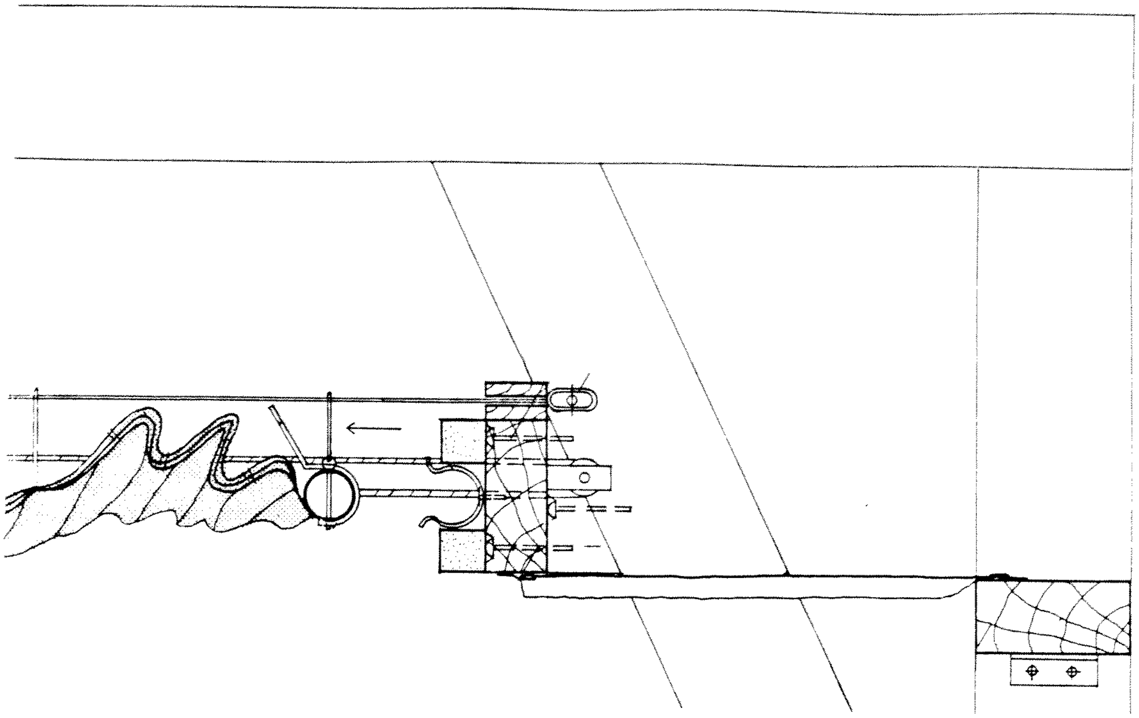
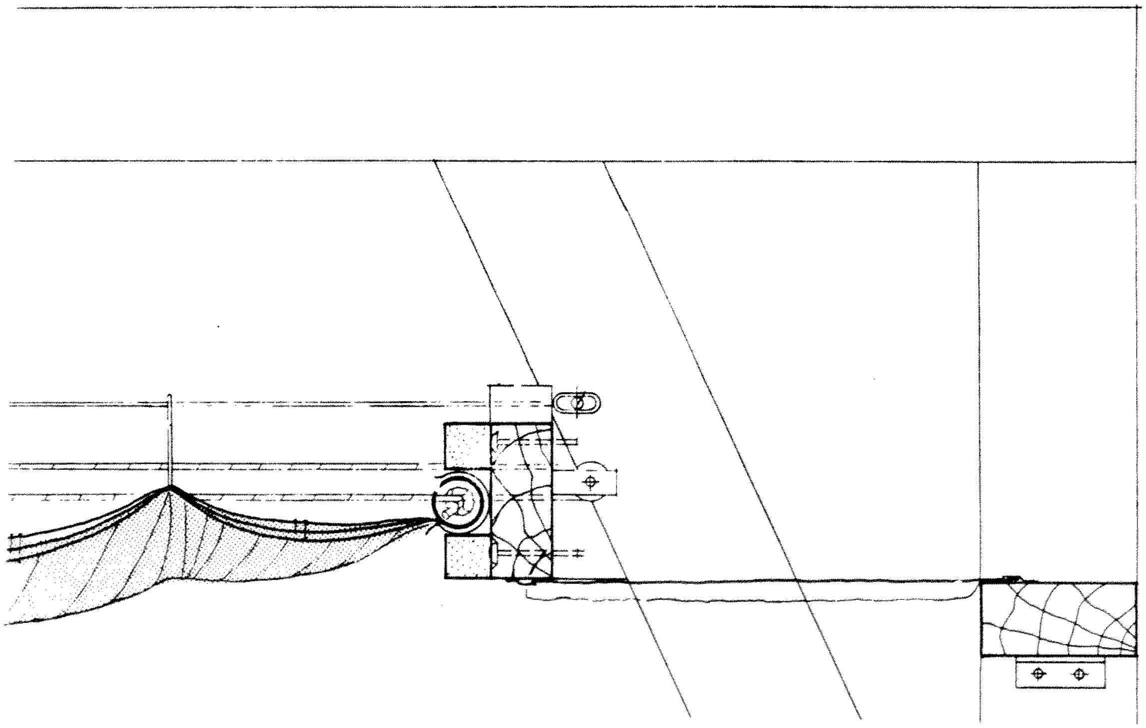


Fig.20
Detail 1
Detail of fixed joint showing motor drive mounted above.



Puller pipe approaching joint showing hangers



Puller pipe in closed position showing pulley rope attachment

Fig.21
Detail 2

Detail of puller pipe leading edge joint

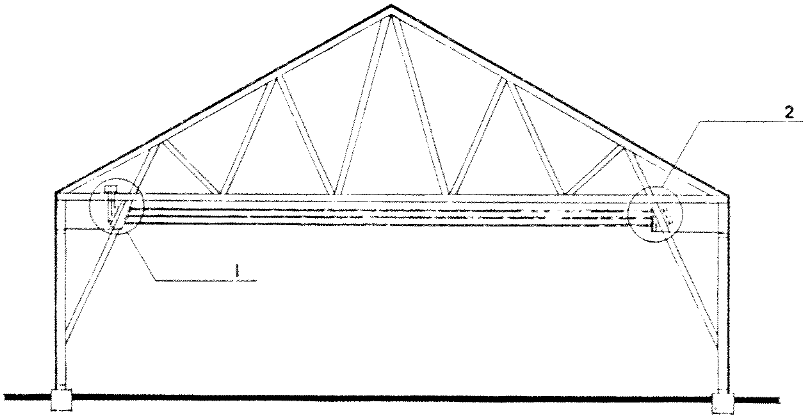
APPENDIX II
MULTI-CABLE OPTION

It was decided to investigate the multi-cable option with a view to comparing cost and operation to the cable supported system. This work took place in June-July so it was not possible to evaluate the thermal performance.

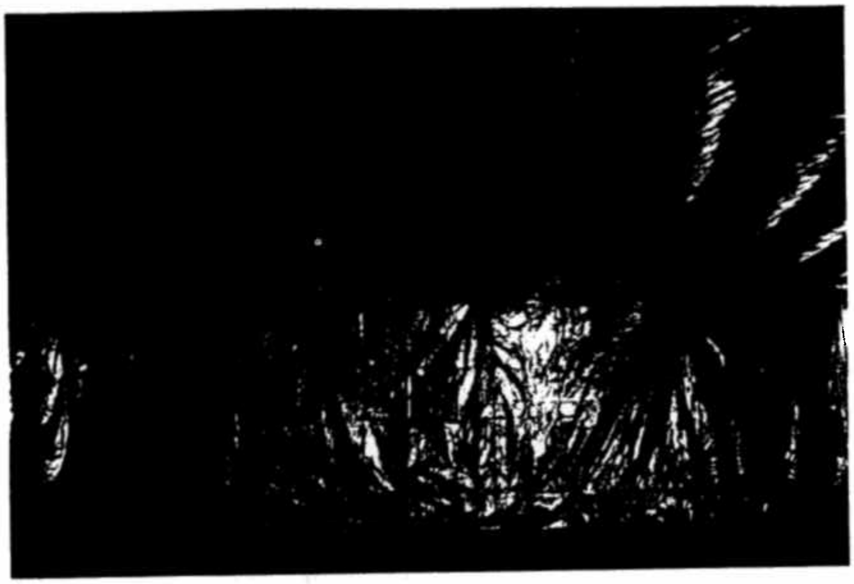
The design of this system dispenses with hangers, instead each layer of curtain is supported by a separate set of cables which are spaced 0.6m apart. The rest of the details of this system are similar to the cable supported option. The cost of the system for the 61m x 10.5m greenhouse are as follows:

Cables, hangers, turnbuckles, tapes	$\$$ 556.49
Curtain material (3 layers)	2305.00
Pulley system & motor drive	1398.80
Puller pipes & lead joints	1066.25
Labour ($\$1.25/\text{m}^2$)	800.63
TOTAL COST	$\$$ 6127.17
TOTAL UNIT COST	$\$ 9.57/\text{m}^2$

The multi-cable option is 20% more expensive than the cable supported option (puller pipes, joints and wires account for this). The advantages are in simpler installation since hangers and layer fasteners are eliminated.



Cross section through greenhouse



Curtain in closed position.

Bottom layer in open position. Note the orderly pattern of folds and relatively small volume of the stored curtain.

Fig.22

MULTI-CABLE CURTAIN

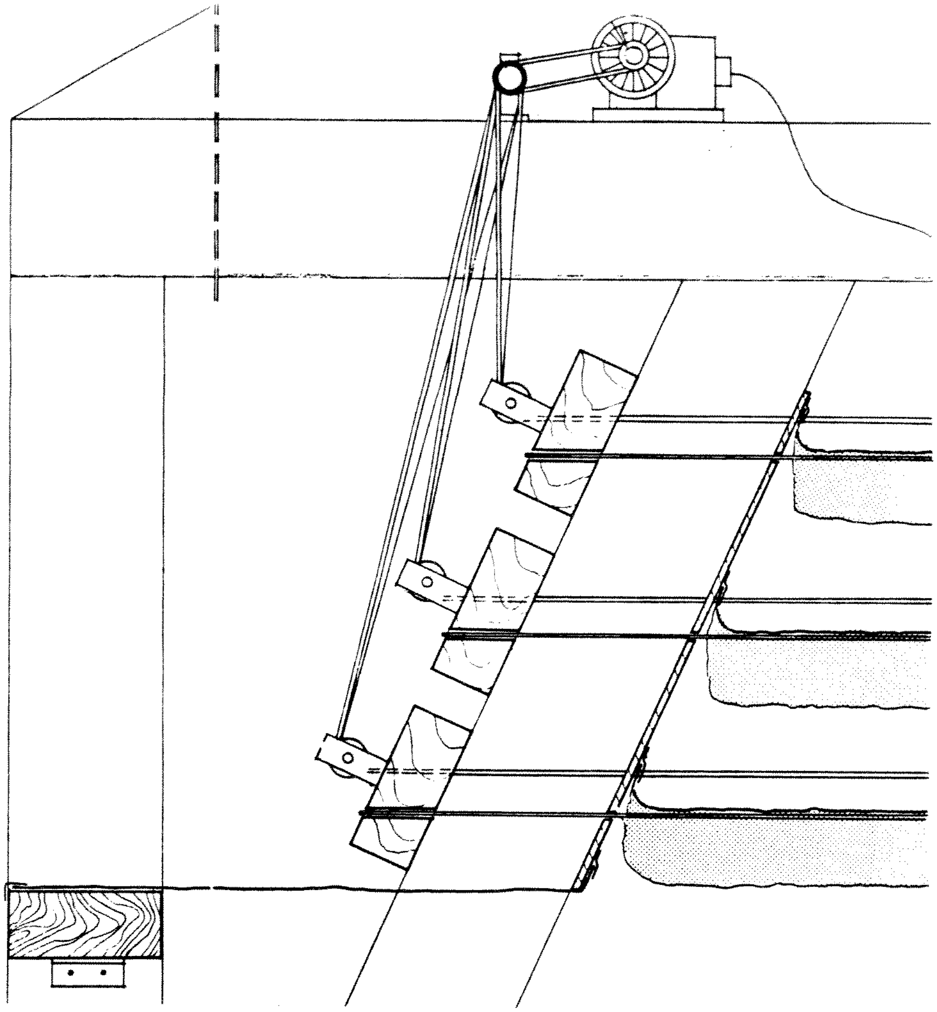


Fig.23

Detail 1

Detail of fixed joint showing motor drive mounted above

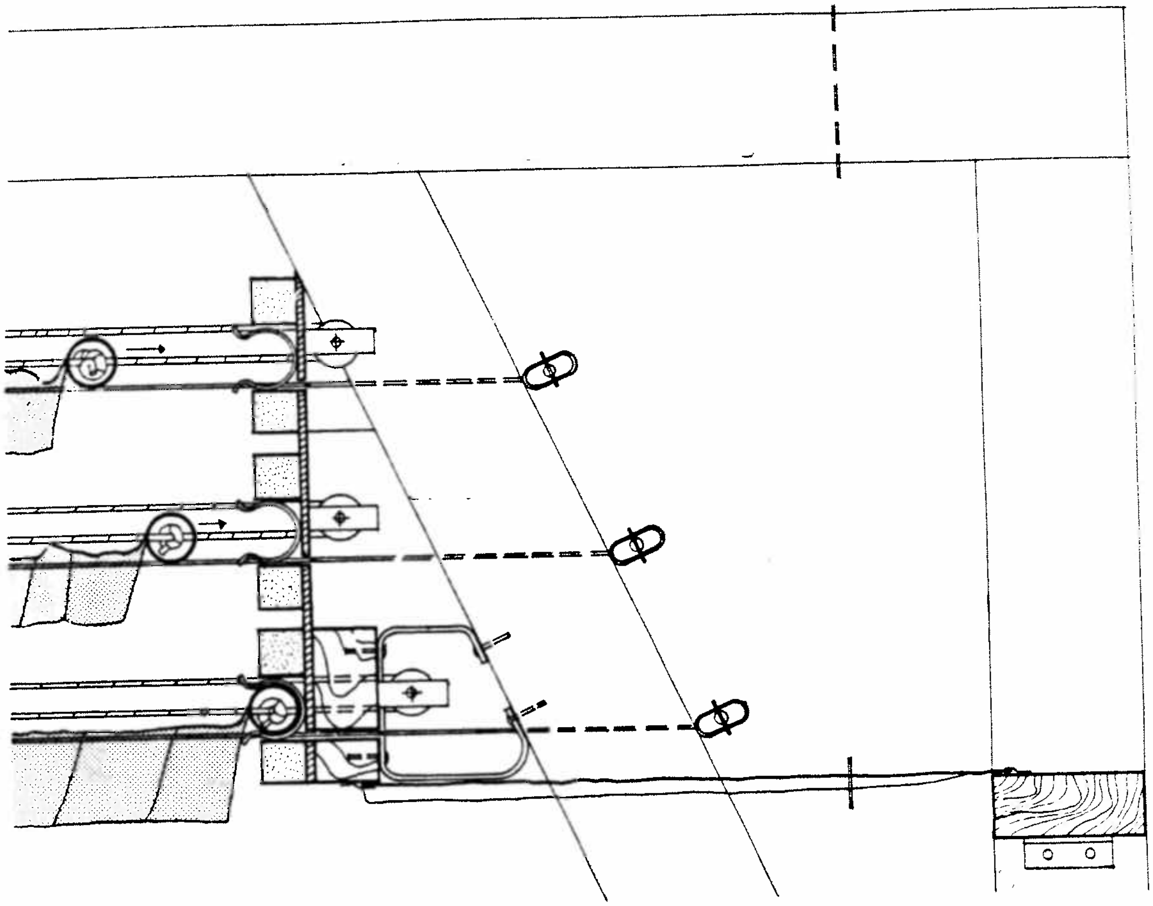


Fig.24

Detail 2

Detail of puller pipe leading edge joint

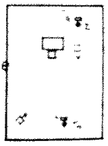
APPENDIX III

MONITORING DATA

SINGLE LAYER/REFLECTIVE SIDE OUT

Chart #	☐ Clear	☐ No Wind	Energy Final	7672	Day/Night
1	☒ Partial Cover	☒ Modrate Wind	Previous	7665	Date Feb. 15, 1980
	☐ Overcast	☐ Windy	Net	7	Humidity Not rec'd

□→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

Min	0	5	10	15	20	25	30	35	40	45	50	55	60	65
T_1	3	3	3	3	3	3	3	3	3	3	3	3	2	2
T_2	3	3	3	3	3	3	2	2	2	2	2	2	2	2
T_3	3	3	4	4	4	4	3	3	3	4	3	3	3	3
T_{Av}	3	3	3.3	3.3	3.3	3.3	2.6	2.6	2.6	3	2.6	2.6	2.3	2.3
T_4	4	4	5	5	5	4	4	4	5	4	4	4	4	4
T_5	4	4	4	4	4	4	4	4	4	4	3	3	3	3
T_{Av}	4	4	4.5	4.5	4.5	4	4	4	4.5	4	3.5	3.5	3.5	3.5
T_6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6
T_7	18	18	18	18	19	18	18	18	18	18	18	18	18	18
T_8														
T_9	-	-	-	-	-	-	-	-	-	21	22	22	22	22
T_{Av}				-										
T_{10}														

Heat Flux Plates

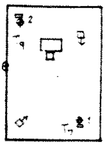
1		2:27	2.84	2.69	2.26	2.68	2.56	2.61	2.44	2.67	2.50	*	2.86	2.84
2		3.53	4.93	4.32	3.99	3.30	3.96	4.38	4.27	4.27	4.39	4.08	4.27	4.05

Observations:

SINGLE LAYER/REFLECTIVE SIDE OUT

Chart #	☒ Clear	☐ No Wind	Energy Final	7695	Day/Night
2	☐ Partial Cover	☒ Modrate Wind	Previous	7688 KWH	Date Feb. 17, 1980
	☐ Overcast	☐ Windy	Net	0007	Humidity Not rec'd

□→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	5	10	15	20	25	30	35	40	45	50	55	60
T_1	0	1	0	0	0	0	0	0	0	1	1	1	1
T_2	0	0	0	0	0	0	0	0	0	0	0	0	0
T_3	0	0	0	0	0	0	0	0	0	0	0	0	1
T_{Av}	0	·3	0	0	0	0	0	0	0	·3	·3	·3	·6
T_4	0	1	1	1	1	1	1	1	1	1	2	1	1
T_5	0	1	0	0	0	0	0	0	0	1	1	1	1
T_{Av}	0	1	·5	·5	·5	·5	·5	·5	·5	1	1.5	1	1
T_6	-9	-9	-9	-8	-8	-9	-8	-8	-8	-8	-8	-8	-8
T_7	18	20	18	18	18	18	18	18	17	18	18	18	18
T_8													
T_9	18	20	17	16	16	16	16	15	16	19	20	18	17
T_{Av}	18	20	17·5	17	17	17	17	17·5	16·5	18·5	19	18	17·5
T_{10}													

Heat Flux Plates

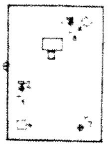
1	*	3.28	3.35	3.09	3.08	3.23	3.23	3.12	3.01	3.70	4.39	3.56	3.28
2	3.09	3.23	3.09	2.53	2.22	2.55	2.51	2.34	2.57	3.71	3.28	2.59	2.64

Observations:

SINGLE LAYER/REFLECTIVE SIDE IN

Chart #	☐ Clear	☐ No Wind	Energy	Final	7711	Day/Night
3	☒ Partial Cover	☐ Mod$\overset{e}{\text{r}}$ate Wind		Previous	7705 KWH	Date Feb. 18, 1980
	☐ Overcast	☒ Windy		Net	6	Humidity Not rec'd

□→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	60	70	80	90	100
T_1	4	4	4	4	4	4	4				
T_2	3	3	3	3	3	3	2				
T_3	4	4	4	4	4	4	3				
T_{Av}											
T_4	5	5	5	5	5	4	4				
T_5	5	5	5	5	5	4	4				
T_{Av}	5	5	5	5	5	4	4				
T_6	-4	-4	-4	-4	-4	-4	-4				
T_7	20	20	22	21	21	21	22				
T_8	19	19	21	20	19	19	19				
T_9	20	19	21	20	20	19	20				
T_{Av}	19·6	19·3	21·3	20·3	20	20	20·3				
T_{10}											

Heat Flux Plates

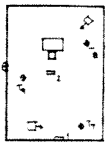
1	1.63	3.74	3.72	3.59	3.62	3.41	3.72				
2	1.87	2.98	3.26	2.58	2.38	2.64	2.41				

Observations:

CONTROL

Chart #	☐ Clear	☒ No Wind	Energy	Final	7854½	Day/Night
4	☐ Partial Cover	☐ Mod$\overset{e}{\text{r}}$ate Wind		Previous	7846½	Date Feb. 19, 1980
	☒ Overcast	☐ Windy		Net	8KWH	Humidity Not rec'd

□→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2
T_1	14	14	14	14	15	15	15						
T_2	13	14	14	14	14	14	14						
T_3	13	14	14	14	14	15	15						
T_{Av}	13.3	14	14	14	14.3	14.6							
T_4	15	15	16	16	16	16	16						
T_5	14	15	15	15	15	15	15						
T_{Av}	14.5	15	15.5	15.5	15.5	15.5	15.5						
T_6	1	1	1	1	1	1	1						
T_7	16	15	16	16	16	16	16						
T_8	15	15	15	15	15	15	15						
T_9	15	14	15	14	14	15	15						
T_{Av}	15.3	14.3	15.3	15	15	15.3							
T_{10}													

Heat Flux Plates

1	3.56	.3.46	3.66	3.53	3.56	3.68	3.32						
2	4.65	4.45	4.79	4.67	4.53	4.34	4.75						

Observations:

SINGLE LAYER/REFLECTIVE SIDE IN

☐- Heater
▬ H.F.Plate
● T.Couple
Recorder

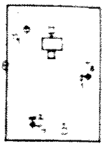


Chart # 5	☐ Clear	☒ No Wind	Energy	Final	7980
	☐ Partial Cover	☐ Modrate Wind		Previous	7975
	☒ Overcast	☐ Windy		Net	5

Day/Night
Date Feb. 20, 1980
Humidity Not rec'd

Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2								
T_1	8	9	9	9	9	9	9	9	9	9	9	9	9								
T_2	8	9	9	9	9	9	9	9	9	9	9	9	9								
T_3	9	9	9	9	9	9	9	9	9	9	9	9	9								
T_{Av}	9	9	9	9	9	9	9	9	9	9	9	9	9								
T_4	10	10	10	11	11	11	11	11	11	11	11	11	11								
T_5	10	10	10	10	10	10	10	10	10	10	10	10	10								
T_{Av}	10	10	10	10·5	10·5	10·5	10·5	10·5	10·5	10·5	10·5	10·5	10·5								
T_6	3	3	3	3	3	3	3	3	3	3	3	3	3								
T_7	19	20	21	20	20	20	20	20	20	20	20	20	19								
T_8	19	20	21	21	21	20	20	20	20	21	20	20	20								
T_9	20	21	21	21	21	21	21	20	20	21	20	20	19								
T_{Av}	19.6	20·3	21	20·6	20·6	20·3	20·3	20	20	20·6	20	20	19·6								
T_{10}																					

Heat Flux Plates

1	2.49	1.40	2.74	1.53	1.90	1.62	2.18	1.62	1.79	2.26	1.43	2.56	1.41								
2	2.87	1.51	3.79	1.59	3.64	1.62	2.70	1.74	2.08	2.39	1.40	2.35	1.23								

Observations: Even though the temperature was maintained within plus/minus 1/2 C° when ever the heater fan was turned on the readings on heatflux plates jumped up by approx. 3.5mV.

SINGLE LAYER/REFLECTIVE SIDE IN

☐- Heater
▬ H.F.Plate
● T.Couple
Recorder

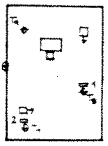


Chart # 6	☒ Clear	☐ No Wind	Energy	Final	8197
	☐ Partial Cover	☒ Modrate Wind		Previous	8185
	☐ Overcast	☐ Windy		Net	12

Day/Night
Date Feb. 21, 1980
Humidity Not Rec'd

Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2	10							
T_1	1	1	0	0	0	0	0	0	0	0	0	0	0	0							
T_2	1	1	1	0	0	0	0	0	0	0	0	0	0	0							
T_3	1	1	1	1	0	1	1	1	1	0	0	0	0	.0							
T_{Av}	1	1	1	0.3	0	0.3	0.3	0.3	0.3	0	0	0	0								
T_4	2	2	-2	2	2	2	2	2	2	1	1	1	1	1							
T_5	2	2	1	1	1	1	1	1	1	1	0	0	1	0							
T_{Av}	2	2	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1	0.5	0.5	1								
T_6	-9	-10	-9	-9	-9	-9	-9	-10	-10	-10	-10	-10	-10	-10							
T_7	22	21	21	19	19	19	21	21	20	19	19	19	19	19							
T_8	22	22	21	20	19	19	21	22	21	21	20	21	21	21							
T_9	22	21	21	20	19	20	22	22	21	20	20	20	20	20							
T_{Av}	22	21·3	21	19·6	19	19·3	21·3	21·6	20·6	20	2.3	20	20	20							
T_{10}																					

Heat Flux Plates

1	4.91	4.43	*	3.32	4.23	5.44	5.15	4.79	4.68	*	*	*	5.03	4.56							
2	4.50	4.55	6.4	3.22	3.58	6.14	6.19	4.47	4.93	4.42	4.21	6.17	4.42	4.50							

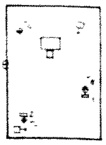
Observations:

SINGLE LAYER/REFLECTIVE SIDE IN

Chart # 7	☐ Clear ☐ Partial Cover ☒ Overcast	☐ No Wind ☒ Moderate Wind ☐ Windy	Energy	Final Previous Net	8688 8680 0008

Day/Night
Date Feb. 24, 1980
Humidity Not rec'd

☐ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2
T_1	9	8	8	8	8	8	7	7	7	7	8	8	7
T_2	8	8	8	7	7	7	7	7	7	7	7	7	7
T_3	9	8	9	8	8	8	8	8	8	8	8	8	8
T_{Av}	8.6	8	8.3	7.6	7.6	7.6	7.6	7.3	7.3	7.3	7.6	7.6	7.3
T_4	10	10	10	10	9	9	9	9	9	9	9	9	9
T_5	10	10	10	9	8	9	9	9	9	9	9	9	9
T_{Av}	10	10	10	9.5	8.5	9	9	9	9	9	9	9	9
T_6	0	0	0	0	0	0	0	0	0	0	0	0	0
T_7	22	22	22	22	22	22	22	23	23	23	22	22	23
T_8	23	22	23	23	22	23	23	23	23	23	23	23	23
T_9	23	22	23	22	23	23	23	23	23	23	23	23	23
T_{Av}	23	22	22.6	22.3	22.3	22.6	22.6	23	23	23	23	22.6	23
T_{10}													

Heat Flux Plates

1	*	2.70	3.75	2.41	2.91	3.75	2.58	3.93	3.99	3.39	3.14	3.49	3.39
2	*	2.54	3.61	2.18	3.59	4.11	3.74	4.51	4.33	3.32	3.40	3.83	3.01

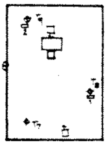
Observations:

TWO LAYERS /REFLECTIVE SIDE IN (BOTH LAYERS)

Chart # 8	☒ Clear ☐ Partial Cover ☐ Overcast	☐ No Wind ☒ Moderate Wind ☐ Windy	Energy	Final Previous Net	8762 8757½ 4½

Day/Night
Date Feb. 25, 1980
Humidity Not rec'd

☐ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	1
T_1	1	0	0	1	1	0	0
T_2	1	1	1	1	1	1	1
T_3	2	2	2	2	2	1	2
T_{Av}	1.6	1	1	1.3	1.3	.6	1
T_4	2	2	-2	2	2	1	1
T_5	1	1	1	1	1	0	0
T_{Av}	1.3	1.5	1.5	1.5	1.5	.5	.5
T_6	-10	-9	-9	-9	-9	-9	-9
T_7	23	22	21	21	21	20	21
T_8	22	21	21	21	22	21	21
T_9	23	22	22	23	23	21	22
T_{Av}	22.6	21.6	21.3	21.6	22	21.6	22.3
T_{10}							

Heat Flux Plates

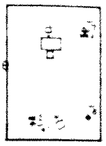
1	2.71	1.94	2.69	2.99	1.13	1.98	3.23
2	3.32	2.22	2.41	2.49	2.53	2.63	3.23

Observations:

TWO LAYERS/ REFLECTIVE SIDE IN (BOTH LAYERS)

Chart #	☒ Clear	☐ No Wind	Energy	Final	9934	Day/Night
9	☐ Partial Cover	☒ Mod$\overset{e}{r}$ate Wind		Previous	9919	Date Feb. 26, 1980
	☐ Overcast	☐ Windy		Net	0015	Humidity 55%

☐→ Heater
▬ H.F.Plate
● T.Couple
☐ Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2	10							
T_1	-1	-0	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1							
T_2	-1	-1	-1	-1	-1	-1	0	-1	-1	0	-1	-1	-1	-1							
T_3	0	0	0	0	0	0	0	0	0	0	0	0	0	·0							
T_{Av}	-6	-.3	-0.6	-0.6	-0.6	-0.6	-0.3	-0.6	-0.3	-0.6	-0.6	-0.6	-0.6	-0.6							
T_4	0	0	0	0	0	0	0	0	0	0	0	0	0	0							
T_5	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1	-1							
T_{Av}	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5	-0.5							
T_6	-16	-15	-14	-14	-15	-15	-15	-15	-15	-15	-15	-15	-15	-15							
T_7	23	24	21	20	22	23	24	24	24	24	24	25	25	24							
T_8	22	24	20	19	21	22	22	22	22	23	23	23	23	23							
T_9	22	22	21	19	19	20	20	21	21	21	21	21	22	21							
T_{Av}	22.3	23.3	20.6	19.3	20.6	21.6	22	22.3	22.3	22.6	22.6	23	23.3	22.6							
T_{10}																					

Heat Flux Plates

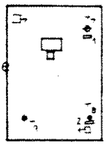
1	*	3.92	3.65	3.90	4.02	4.50	4.48	4.17	4.62	4.36	4.39	3.73	4.32	3.99							
2	*	4.03	3.40	3.36	3.54	3.48	3.46	3.13	3.34	3.01	3.09	2.93	3.18	3.13							

Observations:

TWO LAYERS/REFLECTIVE SIDE IN (BOTH LAYERS)

Chart #	☐ Clear	☐ No Wind	Energy	Final	9188.5	Day/Night
10A	☐ Partial Cover	☒ Mod$\overset{e}{r}$ate Wind		Previous	9179.0	Date Feb. 27, 1980
	☒ Overcast	☐ Windy		Net	815	Humidity 55%

☐→ Heater
▬ H.F.Plate
● T.Couple
☐ Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2								
T_1	5	5	5	4	4	4	4	4	3	3	3	3	3								
T_2	4	4	3	3	3	3	3	3	2	2	2	2	2								
T_3	6	6	5	5	5	4	4	4	4	4	3	4	3								
T_{Av}	5	5	4.3	4	4	3.6	3.6	3.6	3	3	2.6	3	2.6								
T_4	6	6	6	6	5	5	5	5	4	4	4	4	4								
T_5	6	6	5	5	5	4	4	4	4	3	3	3	3								
T_{Av}	6	6	5.5	5.5	5	4.5	4.5	4.5	4	3.5	3.5	3.5	3.5								
T_6	-10	-9	-9	-9	-9	-9	-9	-10	-10	-10	-10	-10	-10								
T_7	26	24	22	20	20	20	20	21	17	19	20	20	19								
T_8	24	22	20	20	19	20	20	20	17	20	19	19	19								
T_9	24	23	22	21	21	21	21	22	19	20	21	20	20								
T_{Av}	24.6	23	21.3	20.3	20	20.6	20.3	21.0	17.6	19.6	20	19.6	19.3								
T_{10}																					

Heat Flux Plates

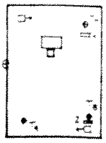
1	2.30	2.13	1.97	2.03	1.86	2.03	2.09	3.53	1.38	3.23	2.29	2.49	1.96								
2	2.79	2.13	2.09	2.22	1.91	2.08	2.18	3.14	1.05	2.81	2.54	2.27	2.37								

Observations: The most of condensation took place along the lower half of the vertical curtain. Later on in the experiment when the temperature was allowed to drop the condensate did deposite it self on the upper part of the vertical curtain but there was no condensation at all on the double-layer horizontel curtain.

DOUBLE LAYERS/ REFLECTIVE SIDE IN

Chart #	☐ Clear	☐ No Wind	Energy	Final		Day/Night
B	☐ Partial Cover	☐ Modrate Wind		Previous		Date Feb. 27, 1980
	☐ Overcast	☐ Windy		Net		Humidity 60%

□→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	1
T_1	3	2	2	1	0	0	0
T_2	2	2	1	0	0	0	0
T_3	3	3	2	1	1	0	0
T_{Av}	2.6	2.3	1.3	.6	.3	0	0
T_4	4	3	-3	2	1	0	0
T_5	3	3	2	1	1	0	0
T_{Av}	3.5	3	2.5	1.5	1	0	0
T_6	-10	-10	-10	-10	-10	-10	-11
T_7	19	15	12	11	10	9	9
T_8	19	16	13	12	10	9	9
T_9	20	18	16	13	12	10	10
T_{Av}							
T_{10}							

Heat Flux Plates

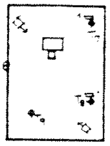
1	2.11	1.38	1.47	1.21	1.17	1.21	1.09
2	2.53	1.18	1.33	1.25	1.20	1.21	1.24

Observations: This was a specil test in which the inside temperature was allowed to droo for one hour in order to find out if just two layer curtain would prevent the formation of condensate even when the temp. was allowed to drop redically. It was observed that two layershuve suffeciant thermal resistance to prevent the condensation.

TWO LAYERS/ REFLECTIVE SIDE IN (BOTH LAYERS)

Chart #	☒ Clear	☐ No Wind	Energy	Final	9243	Day/Night
11	☐ Partial Cover	☒ Modrate Wind		Previous	9231	Date Feb. 28, 1980
	☐ Overcast	☐ Windy		Net	0021	Humidity 55%-60%

□→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2
T_1	0	0	0	0	0	0	0	0	0	0	0	-1	-1
T_2	0	0	0	0	0	0	0	0	0	0	0	0	0
T_3	1	1	1	0	0	0	0	0	0	0	0	0	0
T_{Av}	0.3	0.3	0.3	0	0	0	0	0	0	0	0	0.3	0.3
T_4	1	1	-1	0	0	0	0	0	0	0	0	0	0
T_5	0	0	0	0	0	0	0	0	0	0	0	0	0
T_{Av}	0.5	0.5	0.5	0	0	0	0	0	0	0	0	0	0
T_6	-13	-13	-12	-13	-13	-13	-13	-14	-14	-14	-14	-14	-14
T_7	23	22	22	21	22	22	22	23	21	22	23	22	20
T_8	21	21	21	21	22	21	21	23	20	21	22	21	20
T_9	22	22	21	21	22	21	21	21	20	21	22	21	20
T_{Av}	21	21.6	21.3	21	22	21.3	21.3	21.3	22	20.3	22.3	21.3	20
T_{10}													

Heat Flux Plates

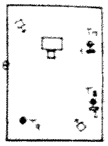
1	*	*	3.05	3.04	4.65	2.95	3.99	3.38	3.24	3.25	4.02	3.22	3.18
2	*	2.80	2.85	2.98	3.66	2.61	3.54	3.55	2.91	3.67	3.39	2.94	3.08

Observations:

TWO LAYERS/REFLECTIVE SIDE IN

Chart #	☒ Clear	☐ No Wind	Energy Final	0721	Day/Night
12	☐ Partial Cover	☒ Moderate Wind	Previous	0713½	Date March 2, 1980
	☐ Overcast	☐ Windy	Net	0007½	Humidity 50%

☐→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	60														
T_1	-4	-3	-3	-2	-2	-2	-2														
T_2	-4	-3	-3	-2	-2	-2	-2														
T_3	-3	-2	-2	-2	-1	-1	-1														
T_{Av}																					
T_4	-3	-2	-1	-1	-1	-1	-1														
T_5	-3	-2	-2	-2	-2	-2	-2														
T_{Av}																					
T_6	-15	-13	-14	-14	-13	-13	-13														
T_7	19	19	19	21	19	19	20														
T_8	19	18	19	20	18	19	19														
T_9	19	18	19	19	18	19	19														
T_{Av}	19	18.3	19	20	18.3	19	19.0														
T_{10}																					

Heat Flux Plates

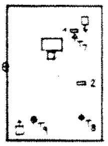
1	3.75	4.14	2.93	3.75	3.35	3.87															
2	3.32	3.19	3.14	2.76	3.08	3.19															

Observations:

TWO LAYERS/ REFLECTIVE SIDE IN (BOTH LAYERS)

Chart #	☒ Clear	☐ No Wind	Energy Final	888.8	Day/Night
13	☐ Partial Cover	☒ Moderate Wind	Previous	0876.5	Date March 3, 1980
	☐ Overcast	☐ Windy	Net	012.3	Humidity 60%-60%

☐→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2	10	20	30	40	50	3		
T_1	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2		
T_2	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2	2	2		
T_3	4	4	4	3	3	3	3	3	3	3	3	3	2	2	2	2	2	2	2		
T_{Av}	3.3	3.3	3.3	3	3	2.6	2.6	2.3	2.3	2.3	2.3	2.3	2	2	2	2	2	2	2		
T_4	4	4	4	4	4	3	3	3	3	3	3	3	3	2	2	2	2	2	2		
T_5	3	3	3	3	3	3	3	2	2	2	2	2	2	2	2	2	2	2	2		
T_{Av}	3.5	3.5	3.5	3.5	3.5	3	3	2.5	2.5	2.5	2.5	2.5	2.5	2	2	2	2	2	2		
T_6	-6	-5	-5	-5	-5	-5	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4	-4		
T_7	26	25	24	19	20	20	28	20	20	20	20	19	20	20	20	21	21	20	19		
T_8	25	24	23	19	20	21	20	20	20	20	20	19	20	20	20	21	21	21	21		
T_9	26	25	23	20	20	21	20	19	19	20	20	20	19	19	20	21	21	21	21		
T_{Av}	25.6	24.6	23.3	19.6	20	20.6	20	19.6	19.6	20	20	19.3	19.6	19.6	20	21	21	20.6	20.3		
T_{10}																					

Heat Flux Plates

1	1.98	1.90	1.59	1.19	1.97	1.97	1.57	1.76	1.88	1.85	1.78	1.61	1.57	1.54	1.41	1.77	1.87	1.96	1.74		
2	1.99	3.14	1.77	1.57	2.10	2.13	1.99	1.79	1.93	1.05	2.06	1.59	1.99	2.04	2.33	1.69	1.99	1.81	1.63		

Observations:

THREE LAYERS/TWO REFLECTIVE SIDES FACING IN & ONE FACING OUT

☐→ Heater
═ H.F.Plate
● T.Couple
Recorder

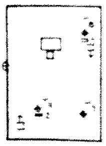


Chart # 14	☒ Clear	☐ No Wind	Energy Final	956.5	Day/Night
	☐ Partial Cover	☒ Modrate Wind	Previous	947.5	Date March 4 1980
	☐ Overcast	☐ Windy	Net	9.0	Humidity 60%

Temperature

	0	10	20	30	40	50	60	70	80	90	100	110	120
T_1	5	4	5	5	5	5	5	4	4	4	4	4	
T_2	5	5	5	5	5	5	5	5	5	4	4	4	
T_3	6	5	6	5	6	6	5	5	5	5	5	5	
T_{Av}	5.3	4.6	5.3	5	5.3	5.3	5	4.6	4.6	4.3	4.3	4.3	
T_4	6	5	5	5	5	5	5	5	5	5	5	5	
T_5	5	4	5	5	5	5	5	4	4	5	4	4	
T_{Av}	5.5	4.5	5	5	5	5	5	4.5	4.5	5	4.5	4.5	
T_6	-2	-1	-1	-1	-1	-1	-1	-1	-1	-2	-2	-2	
T_7	20	21	21	21	21	20	21	21	21	21	21	.22	
T_8	19	22	22	22	23	23	23	22	21	21	21	20	
T_9	21	21	21	21	20	20	20	21	21	21	21	21	
T_{Av}	20	21.3	21.3	21.3	21.3	21	21.3	21.3	21	21	21	21	
T_{10}													

Heat Flux Plates

1	2.03	1.73	1.64	1.56	1.46	1.77	1.67	1.57	1.53	1.49	1.64	1.60
2	2.56	1.21	1.50	1.38	1.41	1.33	1.67	1.42	1.28	1.30	1.52	1.44

Observations:

TRIPLE LAYERS/REFLECTIVE SIDE IN

☐→ Heater
═ H.F.Plate
● T.Couple
Recorder

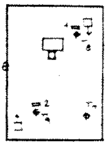


Chart # 15	☐ Clear	☐ No Wind	Energy Final	0081	Day/Night
	☐ Partial Cover	☒ Modrate Wind	Previous	0075	Date March 5, 1980
	☒ Overcast (rain)	☐ Windy	Net	6	Humidity 60%-65%

Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2	10
T_1	7	7	7	7	7	7	7	7	6	6	6	6	6	6
T_2	7	6	6	6	7	7	7	7	7	6	6	6	6	6
T_3	7	7	7	7	7	7	7	7	7	7	7	6	6	.6
T_{Av}	7	6.6	6.6	6.6	7	7	7	7	6.6	6.3	6.3	6	6	6
T_4	7	7	7	7	7	8	7	7	7	7	7	6	7	6
T_5	6	7	6	6	7	7	7	7	6	6	6	6	6	6
T_{Av}	6.5	7	6.5	6.5	7	7.5	7	7	6.5	6.3	6.5	6	6.5	6
T_6	0	0	0	0	0	0	0	0	0	0	0	0	0	0
T_7	27	24	22	22	22	22	21	21	21	21	22	20	22	20
T_8	29	22	23	22	22	22	22	2k	22	22	22	2k	22	19
T_9	28	24	22	23	22	22	22	22	22	21	22	21	21	20
T_{Av}	28	23.3	22.3	22.3	22	22	21.6	21.3	21.6	21.3	22	20.6	21.6	19.6
T_{10}														

Heat Flux Plates

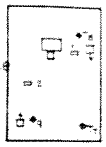
1	1.54	1.24	1.71	1.75	1.57	1.16	1.24	1.10	1.40	1.47	1.45	1.39	1.16	1.18
2	1.85	.88	1.96	1.90	1.57	.71	1.05	1.00	1.14	1.58	1.21	1.42	1.27	1.07

Observations: The heat was not turned on for the first 25min.

TRIPLE LAYER/REFLECTIVE SIDE IN

Chart #	☐ Clear	☐ No Wind	Energy	Final	0201.3	Day/Night
16	☒ Partial Cover	☒ Mod$\overset{e}{r}$ate Wind		Previous	0292.8	Date March 16, 1980
	☐ Overcast	☐ Windy		Net	8.5	Humidity 60%-65%

☐→ Heater
▭ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2	10
T_1	4	4	4	4	4	4	4	4	4	4	4	4	4	
T_2	4	4	4	4	4	4	4	4	4	4	4	4	4	
T_3	4	4	5	-5	5	5	5	5	5	5	5	5	5	
T_{Av}	4	4	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	4.3	
T_4	4	4	-4	4	5	5	5	4	4	4	4	4	4	
T_5	4	4	4	4	4	4	4	4	4	4	4	4	4	
T_{Av}	4	4	4	4	4.5	4.5	4.5	4	4	4	4	4	4	
T_6	-5	-5	-4	-4	-4	-4	-4	-4	-3	-3	-3	-3	-3	
T_7	22	21	22	22	23	23	23	23	23	23	23	22	22	
T_8	23	22	22	22	22	22	22	22	22	22	22	22	22	
T_9	23	22	22	22	23	23	23	23	23	22	23	22	23	
T_{Av}	23.6	21.6	22	22	22.6	22.6	22.6	22.6	22.6	22.5	22.6	22	22.6	
T_{10}														

Heat Flux Plates

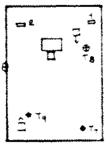
1	1.61	1.64	1.71	1.73	1.70	1.63	1.64	1.72	*	1.69	1.66	1.62	1.63
2	*	1.60	1.66	1.65	1.70	1.56	1.68	1.62	1.60	1.68	1.61	1.56	1.51

Observations: The heat was not turned on for the first 10min.

THREE LAYERS/TWO REFLECTIVE SIDES FACING IN & ONE FACING OUT

Chart #	☐ Clear	☐ No Wind	Energy	Final	0581	D$\overset{xy}{a}$y/Night
17	☐ Partial Cover	☒ Mod$\overset{e}{r}$ate Wind		Previous	0573	Date March 10 1980
	☑ Overcast (rain)	☐ Windy		Net	8	Humidity 60%-65%

☐→ Heater
▭ H.F.Plate
● T.Couple
Recorder



Temperature

	A				B								
	0	10	20	30	40	50	60	70	80	90	100	110	120
T_1	8	9	9	8	8	8	8	8	8	8	8	8	8
T_2	9	9	9	9	9	9	9	9	9	9	9	9	9
T_3	9	9	9	9	9	9	9	9	9	9	9	9	9
T_{Av}	8.6	9	9	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6	8.6
T_4	9	9	9	9	9	9	9	9	9	9	9	9	9
T_5	8	8	8	8	8	8	8	8	8	8	8	8	8
T_{Av}	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5	8.5
T_6	1	1	2	2	2	2	2	2	2	2	2	2	2
T_7	24	24	23	24	23	23	23	23	24	24	24	24	24
T_8	25	25	24	24	24	24	24	23	23	23	23	23	24
T_9	23	24	23	23	23	23	23	24	24	25	25	25	25
T_{Av}	24	24.3	23.3	23.6	23.3	23.3	23.3	23.3	23.6	24	24	24	24.3
T_{10}													

Heat Flux Plates

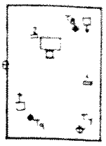
1	2.20	2.05	1.53	1.75	3.47	3.22	3.49	3.03	3.26	3.22	3.04	3.17	3.09
2	1.87	1.66	1.36	1.46	1.46	1.48	1.45	1.24	1.29	1.22	1.24	1.28	1.21

Observations: The heat was not turned on for the first 10min.

FOUR LAYERS/THREE REFLECTIVE SIDE IN & ONE REFLECTIVED SIDE OUT

Chart #	☒ Clear	☐ No Wind	Energy	Final	0646.5	Day/Night
18	☐ Partial Cover	☐ Mod^{e}rate Wind		Previous	0638	Date March 11, 1980
	☐ Overcast	☒ Windy		Net	8.5	Humidity 68%

☐- Heater
▬ H.F.Plate
● T.Couple
☐ Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2								
T_1	1	1	1	1	2	2	2	2	2	2	2	2	2								
T_2	1	1	1	1	2	2	2	2	2	2	2	2	2								
T_3	1	1	1	2	2	2	2	2	2	2	2	3	2								
T_{Av}	1	1	1	1.3	2	2	2	2	2	2	2	2.3	2								
T_4	1	1	1	1	2	2	2	2	2	2	2	2	2								
T_5	0	1	0	1	1	1	1	1	1	1	1	1	1								
T_{Av}	.5	1	.5	1	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5	1.5								
T_6	-5	-5	-6	-6	-6	-6	-6	-6	-6	-6	-6	-6	-7								
T_7	16	17	17	18	19	19	19	19	20	20	20	20	19								
T_8	14	16	16	17	17	17	17	17	18	18	18	18	18								
T_9	16	17	17	18	19	20	20	20	20	20	20	21	19								
T_{Av}	15.3	16.6	16.6	17.6	18.3	18.6	18.6	18.6	19.3	19.3	19.3	19.6	18.6								
T_{10}																					

Heat Flux Plates

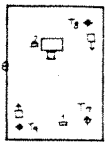
1	1.81	1.76	1.72	1.70	1.64	1.76	1.85	1.90	1.86	1.95	1.82	1.94	1.60								
2	1.50	1.50	1.30	1.33	1.25	1.32	1.30	1.40	1.30	1.37	1.44	1.39	1.15								

Observations:

FOUR LAYERS/THREE REFLECTIVE SIDES IN & ONE REFLECTIVE SIDE OUT

Chart #	☒ Clear	☐ No Wind	Energy	Final	1744.0	Day/Night
19	☐ Partial Cover	☒ Mod^{e}rate Wind		Previous	1733.2	Date March 12, 1980
	☐ Overcast	☐ Windy		Net	10.8	Humidity 65% - 60%

☐- Heater
▬ H.F.Plate
● T.Couple
☐ Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2								
T_1	-1	-1	-1	0	0	0	0	0	0	0	0	0	0								
T_2	-2	-1	-1	0	0	0	0	0	0	0	0	0	0								
T_3	0	0	0	0	0	0	0	0	0	0	0	0	0								
T_{Av}	-1	-.6	-.6	0	0	0	0	0	0	0	0	0	0								
T_4	-1	0	0	0	0	0	0	0	0	0	0	0	0								
T_5	-1	-1	-1	0	-1	-1	0	0	-1	0	0	-1	0								
T_{Av}	-1	-.5	-.5	0	-.5	-.5	0	0	-.5	0	0	-.5	0								
T_6	-10	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9	-9								
T_7	19	19	20	19	21	20	20	21	20	20	20	20	19								
T_8	17	18	19	19	19	19	19	20	20	19	19	19	19								
T_9	17	19	20	20	20	20	19	20	21	21	20	20	19								
T_{Av}	17.3	18.6	19.6	19.3	20	19.6	19.3	20.3	20.3	20	19.6	19.6	19								
T_{10}																					

Heat Flux Plates

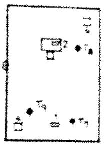
1	1.73	1.94	2.05	1.84	2.14	1.98	1.83	2.13	1.93	1.76	1.87	1.94	1.77								
2	*	1.98	1.83	1.86	2.02	1.93	1.94	2.05	1.76	1.69	1.60	1.62	1.93								

Observations:

FOUR LAYERS/THREE REFLECTIVE SIDE IN & ONE REFLECTIVE SIDE OUT

Chart #	☐ Clear	☐ No Wind	Energy	Final	840.2	Day/Night
20	☐ Partial Cover	☒ Moderate Wind		Previous	0832.2	Date March 13, 1980
	☒ Overcast	☐ Windy		Net	8.0	Humidity 60%

☐→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2								
T_1	4	4	4	4	4	5	5	5	5	5	4	4	4								
T_2	4	4	4	4	4	4	4	4	4	4	3	3	3								
T_3	5	5	5	5	5	5	5	5	5	5	5	5	5								
T_{Av}	4.3	4.3	4.3	4.3	4.3	4.6	4.6	4.6	4.6	4.6	4	4	4								
T_4	5	5	5	5	5	5	5	5	5	5	5	5	5								
T_5	4	4	4	4	4	4	4	4	4	4	4	4	4								
T_{Av}	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.5								
T_6	-6	-6	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5	-5								
T_7	22	22	22	23	23	24	24	25	25	22	22	21	22								
T_8	20	20	20	20	21	21	21	21	21	21	23	22	21								
T_9	22	23	21	23	23	24	24	24	25	22	22	21	22								
T_{Av}	21.3	21.6	21	22	22.3	23	23	23.3	23.6	21.3	22.3	21.3	21.6								
T_{10}																					

Heat Flux Plates

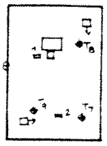
1	1.53	1.48	1.42	1.73	1.68	1.86	1.86	1.81	1.83	1.19	1.22	1.35	1.69								
2	1.55	1.59	1.57	1.72	1.68	1.67	1.66	1.56	1.55	1.42	1.39	1.62	1.40								

Observations:

FOUR LAYERS/THREE REFLECTIVE LAYERS FACING & ONE FACING OUT

Chart #	☐ Clear	☐ No Wind	Energy	Final	1935	Day/Night
21	☐ Partial Cover	☐ Moderate Wind		Previous	1926.8	Date March 14, 1980
	☒ Overcast	☒ Windy		Net	9.8	Humidity 65%

☐→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2								
T_1	4	4	4	4	4	4	4	4	4	4	4	4	4								
T_2	4	4	5	4	4	4	4	4	4	5	5	5	5								
T_3	5	5	5	5	5	5	5	5	5	5	5	6	6								
T_{Av}																					
T_4	5	5	5	5	5	5	5	5	5	5	5	5	5								
T_5	4	4	4	4	4	4	4	4	4	4	4	4	4								
T_{Av}																					
T_6	-5	-5	-4	-4	-4	-4	-4	-3	-3	-3	-3	-3	-3								
T_7	20	20	21	18	20	20	20	20	20	21	21	21	21								
T_8	21	22	21	19	20	20	20	21	21	21	21	21	21								
T_9	20	20	21	18	19	19	19	20	20	20	20	20	20								
T_{Av}	20.3	20.6	21	18.3	19.6	19.6	19.6	20.3	20.3	20.6	20.6	20.6	20.6								
T_{10}																					

Heat Flux Plates

1	1.51	1.24	1.46	1.23	1.22	1.25	1.36	1.27	1.39	1.22	1.35	1.36	.87								
2	1.51	1.41	1.44	1.52	1.48	1.62	1.57	1.59	1.59	1.63	1.62	1.62	.94								

Observations:

FIVE LAYERS/ONE REFLECTIVE SIDE OUT & FOUR RELECTIVE SIDES IN

☐→ Heater
▬ H.F.Plate
● T.Couple
Recorder

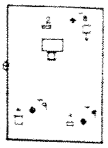


Chart #	☐ Clear	☐ No Wind	Energy	Final	1225.2	Day/Night
22	☒ Partial Cover	☐ Moderate Wind		Previous	1216.0	Date March 18, 1980
	☐ Overcast	☒ Windy		Net	9.2	Humidity 65%

Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2
T_1	2	2	2	3	2	3	3	3	3	3	2	2	2
T_2	2	2	2	3	3	3	3	3	3	3	3	2	3
T_3	2	2	2	2	2	2	2	2	2	2	2	2	2
T_{Av}	2	2	2	2.6	2.3	2.6	2.6	2.6	2.6	2.6	2.3	2	2.3
T_4	2	3	3	3	3	3	3	3	3	3	3	2	3
T_5	1	2	1	1	2	2	2	2	2	2	2	1	2
T_{Av}	1.5	2.5	2	2	2.5	2.5	2.5	2.5	2.5	2.5	2.5	1.5	2.5
T_6	-1	-2	-2	-1	-1	-1	-1	-1	12	12	12	-1	-2
T_7	14	17	19	20	21	22	22	22	24	22	20	17	18
T_8	17	21	20	19	19	19	19	24	27	22	20	18	19
T_9	15	19	20	20	21	21	21	25	27	24	21	18	20
T_{Av}	16.3	19	19.6	19.6	20.3	20.6	20.6	23.6	26	22.3	20.3	17.6	19
T_{10}													

Heat Flux Plates

1	1.32	1.76	1.97	1.80	1.67	1.80	1.78	2.05	2.16	1.66	1.10	.93	1.95
2	1.25	1.30	1.61	1.44	1.39	1.47	1.45	1.67	1.93	1.56	1.20	1.03	1.49

Observations:

FIVE LAYERS/ONE REFLECTIVE SIDE OUT & FOUR REFLECTIVE SIDES IN

☐→ Heater
▬ H.F.Plate
● T.Couple
Recorder

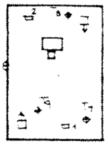


Chart #	☒ Clear	☐ No Wind	Energy	Final		Day/Night
23	☐ Partial Cover	☒ Moderate Wind		Previous	1321.6	Date March 19, 1980
	☐ Overcast	☐ Windy		Net	2	Humidity 60%

Temperature

	0	10	20	30	40	50	1
T_1	10	10	9	9	9	9	8
T_2	10	9	8	9	9	8	8
T_3	10	9	9	9	9	8	8
T_{Av}	10	9.3	8.6	9	9	8.3	8
T_4	12	11	10	10	10	9	9
T_5	11	10	9	9	9	9	8
T_{Av}	11.5	10.5	9.5	9.5	9.5	9	8.5
T_6	0	0	0	0	0	0	0
T_7	27	23	20	20	20	20	20
T_8	27	25	22	21	21	21	21
T_9	27	24	21	21	21	20	20
T_{Av}	27	24	21	20.6	20.6	20.3	20.3
T_{10}							

Heat Flux Plates

1	1.98	1.18	1.23	.93	1.19	1.14	1.12
2	1.70	1.27	1.00	1.09	1.27	1.09	1.13

Observations:

FIVE LAYERS/ONE REFLECTIVE SIDE OUT & FOUR REFLECTIVE SIDES IN

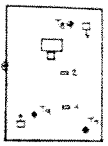
Chart # 24

☐ Clear ☐ No Wind
☐ Partial Cover ☒ Modrate Wind
☒ Overcast ☐ Windy

Energy Final 1350.0
Previous 1344.9
Net 5.1

Day/Night
Date March 20, 1980
Humidity 70%

☐→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2								
T_1	9	9	8	8	8	8	8	8	8	8	8	7	7								
T_2	9	9	9	9	9	9	9	9	8	8	8	8	8								
T_3	9	9	9	9	9	9	9	9	8	8	8	8	8								
T_{Av}	9	9	8.6	8.6	8.6	8.6	8.6	8.6	8	8	8	7.6	7.6								
T_4	9	9	9	9	9	9	9	9	8	8	8	8	8								
T_5	9	9	8	8	8	8	8	8	8	7	7	7	7								
T_{Av}	9	9	8.5	8.5	8.5	8.5	8.5	8.5	8	7.5	7.5	7.5	7.5								
T_6	3	4	3	3	3	3	2	2	2	2	2	2	2								
T_7	19	21	19	19	18	19	19	19	19	19	19	18	19								
T_8	21	21	20	20	19	20	20	20	20	20	20	20	19								
T_9	19	21	19	19	18	19	19	19	19	19	19	19	19								
T_{Av}	19.6	21	19.3	19.3	18.3	19.3	19.3	19.3	19.3	19.3	19.3	19	19								
T_{10}																					

Heat Flux Plates

1	1.07	1.08	.97	.97	.84	1.00	1.16	1.01	1.15	1.06	1.12	1.06	1.10								
2	1.13	.77	.81	.72	.76	.92	.87	.92	.92	.99	.97	.96	.92								

Observations:

FIVE LAYERS/ONE REFLECTIVE SIDE OUT & FOUR REFLECTIVE SIDES IN

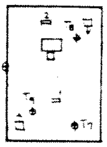
Chart # 25

☐ Clear ☐ No Wind
☐ Partial Cover ☒ Modrate Wind
☒ Overcast ☐ Windy

Energy Final 1472.1
Previous 1467.0
Net 5.1

Day/Night
Date March 27, 1980
Humidity 70%

☐→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2	10	20						
T_1	9	9	10	10	10	10	10	10	10	10	10	10	10	10	10						
T_2	0	10	10	10	10	10	10	10	10	10	10	10	10	10	10						
T_3	0	10	10	10	10	10	10	10	10	10	10	10	10	10	10						
T_{Av}	9	9.6	10	10	10	10	10	10	10	10	10	10	10	10	10						
T_4	9	10	10	10	10	10	10	10	10	10	10	10	10	10	10						
T_5	9	9	10	10	10	9	9	10	10	10	10	10	10	10	10						
T_{Av}	9	9.5	10	10	10	9.5	9.5	10	10	10	10	10	10	10	10						
T_6	6	6	6	6	6	6	6	6	6	6	6	6	6	6	6						
T_7	23	23	22	21	21	21	21	21	20	20	20	20	19	18	17						
T_8	23	23	22	22	21	21	21	21	21	20	20	21	20	19	18						
T_9	22	23	22	22	21	20	21	21	20	20	20	20	19	18	17						
T_{Av}	22.6	23	22	21.6	21	20.6	21	21	20.3	20	20	20.3	19.3	18.3	17.3						
T_{10}																					

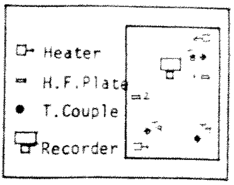
Heat Flux Plates

1	1.34	1.34	1.04	1.03	.78	.98	.99	.91	.91	.76	.76	.75	.69	.59	.50						
2	2.64	2.48	1.45	1.21	1.18	1.14	1.19	1.05	.93	1.05	1.08	.98	.55	.38	.25						

Observations:

FIVE LAYERS/ONE REFLECTIVE SIDE OUT & FOUR REFLECTIVE SIDES IN

Chart #	☒ Clear	☐ No Wind	Energy	Final	1583.3	Day/Night
26	☐ Partial Cover	☒ Modrate Wind		Previous	1588.2	Date March 28, 1980
	☐ Overcast	☐ Windy		Net	5.3	Humidity 67%



Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2	10
T_1	10	10	10	10	10	11	10	11	11	11	11	11	11	11
T_2	10	10	10	11	11	11	11	11	11	11	11	11	11	11
T_3	10	10	10	10	11	11	11	11	11	11	11	11	11	11
T_{Av}	10	10	10	10.3	10.7	11	10.7	11	11	11	11	11	11	11
T_4	11	10	10	11	11	11	11	11	11	11	11	11	11	11
T_5	10	9	10	10	10	10	10	10	10	10	10	10	11	11
T_{Av}	10.5	9.5	10	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	10.5	11	11
T_6	7	7	7	8	8	7	7	8	8	7	7	7	7	7
T_7	20	18	18	20	20	19	19	19	19	19	19	19	19	20
T_8	20	19	20	20	20	20	20	20	20	20	20	20	20	20
T_9	20	19	19	20	19	19	19	19	19	19	19	19	19	20
T_{Av}	20	18.7	19.7	20	19.7	19.3	19.3	19.3	19.3	19.3	19.3	19.3	19.3	20
T_{10}	13	13	13	14	14	14	14	14	14	14	14	14	14	14

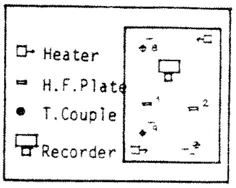
Heat Flux Plates

1	0.22	.30	.33	.37	.42	.39	.37	.36	.41	.35	.33	.39	.42	.38
2	2.74	.74	1.64	2.03	1.95	1.41	1.73	1.53	1.79	1.32	1.37	1.48	1.39	.97

Observations:

THREE LAYERS/NEW CURTAIN TWO REFLECTIVE SIDES FACING IN & ONE FACING OUT

Chart #	☒ Clear	☐ No Wind	Energy	Final		Day/Night
27	☐ Partial Cover	☒ Modrate Wind		Previous	1852.5	Date
	☐ Overcast	☐ Windy		Net	3.3	Humidity 72%



Temperature

	0	10	20	30	40	50	1	10	20	30
T_1	12	12	12	13	13	13	12	12	12	12
T_2	12	12	12	13	13	13	12	12	12	12
T_3	12	12	13	13	13	13	13	12	12	12
T_{Av}	12	13	12.3	13	13	13	12.3	12	12	12
T_4	13	13	14	13	13	13	13	12	12	12
T_5	12	12	13	13	13	12	12	12	12	12
T_{Av}	12.5	12.5	13.5	13	13	12.5	12.5	12	12	12
T_6	11	11	10	10	10	10	9	9	9	9
T_7	15	19	25	21	20	19	20	19	19	18
T_8	16	19	22	23	22	20	21	21	20	19
T_9	18	24	28	23	22	20	21	20	19	19
T_{Av}	16.3	21	25	22.3	21.3	19.6	20.6	20	19.3	18.6
T_{10}	14	14	14	14	14	14	14	14	14	14

Heat Flux Plates

1	*	.25	.69	.79	.59	.47	.56	.55	.40	.28
2	*	.23	.60	.71	.59	.47	.52	.52	.40	.28

Observations: Special test to determine the thermal resistance of the greenhouse floor.

THREE LAYERS/NEW CURTAIN TWO REFLECTIVE SIDES FACING IN & ONE FACING OUT

Heater
H.F.Plate
● T.Couple
Recorder

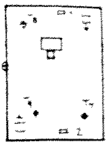


Chart # 28	☐ Clear	☐ No Wind	Energy	Final	1844.8	Day/Night
	☒ Partial Cover	☒ Moderate Wind		Previous	1842.2	Date
	☐ Overcast	☐ Windy		Net	2.6	Humidity

Temperature

	0	10	20	30	40	50	1	10	20	30	40	50	2	10	20
T_1	12	12	12	12	12	12	11	11	10	11	11	10	10	10	9
T_2	12	12	12	12	11	11	11	11	11	11	10	10	10	10	9
T_3	13	13	13	12	12	12	12	11	11	11	11	10	10	10	10
T_{Av}	12.3	12.3	12.3	12	11.6	11.6	11.3	11	10.6	11	10.6	10	10	10	9.3
T_4	12	13	12	12	12	12	12	11	11	11	11	10	10	10	10
T_5	12	12	12	12	11	11	11	11	10	10	11	9	9	9	9
T_{Av}	12	12.5	12	12	11.5	11.5	11.5	11	10.5	10.5	11	9.5	9.5	9.5	9.5
T_6	7	7	7	7	7	7	7	7	7	6	6	6	6	6	6
T_7	31	28	24	22	21	23	22	20	25	24	21	20	23	21	20
T_8	29	27	24	23	21	22	22	21	24	24	22	21	22	21	20
T_9	30	27	25	23	22	22	22	21	24	23	22	20	22	21	20
T_{Av}	30	27.3	24.3	22.6	21.3	22.3	22	20.6	24.3	23.6	21.6	20.3	22.3	21	20
T_{10}	18	18	19	19	19	19	19	19	19	19	19	19	19	19	19

Heat Flux Plates

1	.69	.72	.57	.37	.21	.13	.16	.11	.01	.13	.07	.02	.08	.01	.02
2	1.10	1.06	.87	.65	.50	.39	.34	.25	.21	.24	.18	.11	.08	.11	.06

Observations: Special test to determine the thermal resistance of the greenhouse floor.
The heat was not turned on for the first 45 min.

CONTROL/WITHOUT ANY CURTAINS

Heater
H.F.Plate
● T.Couple
Recorder

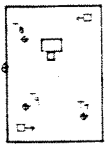


Chart # 29	☐ Clear	☒ No Wind	Energy	Final	2606.6	Day/Night
	☒ Partial Cover	☐ Moderate Wind		Previous	2595.9	Date May 6, 1980
	☐ Overcast	☐ Windy		Net	10.9	Humidity 52%

Temperature

	0.6	10	20	30	40	50	60	70	80	90	100	110	120	130
T_1	23	23	22	22	22	21	21	21	21	22	22	22	21	21
T_2	20	20	20	19	19	19	19	20	19	19	19	19	19	19
T_3	21	21	21	20	20	19	19	20	20	20	20	20	19	19
T_{Av}	21.3	21.3	21.0	20.3	20.3	19.6	19.6	20.3	20.0	20.3	20.3	20.3	19.6	19.6
T_4	24	24	24	23	22	22	22	23	23	22	22	22	22	22
T_5	23	23	22	22	22	22	21	22	22	22	22	22	22	21
T_{Av}	23.5	23.5	23.0	22.5	22.0	22.0	22.5	22.5	22.5	22.0	22.0	22.0	22.0	21.5
T_6	9	9	9	9	9	9	9	9	9	10	10	10	10	10
T_7	23	23	22	22	21	21	21	22	21	21	21	21	21	21
T_8	23	23	23	23	22	22	21	22	22	22	22	22	21	21
T_9	22	22	22	22	21	21	21	21	21	21	21	21	21	21
T_{Av}	22.6	22.6	22.3	22.3	21.3	21.3	21.0	21.6	21.3	21.3	21.3	21.3	21.0	21.0
T_{10}	15	15	15	16	16	16	16	16	16	16	16	17	16	16

Heat Flux Plates

1	4.15	4.32	3.90	3.90	3.39	3.90	3.74	4.17	3.35	2.69	2.51	3.10	3.39	3.75
2	4.81	4.63	4.01	3.96	3.94	3.70	3.58	4.28	3.92	3.35	3.20	3.09	3.37	3.61

Observations:

CONTROL/WITHOUT ANY CURTAINS

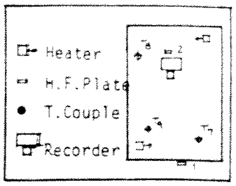


Chart #	☒ Clear	☒ No Wind	Energy Final	2653.6
30	☐ Partial Cover	☐ Modrate Wind	Previous	2638.0
	☐ Overcast	☐ Windy	Net	15.6

Day/Night

Date May 7 1980

Humidity 59%

Temperature

	0	10	20	30	40	50	60	70	80	90	100	110
T_1	20	22	22	22	22	22	22	22	22	22	22	22
T_2	18	19	19	19	19	19	19	19	19	19	19	18
T_3	20	21	21	21	21	21	21	21	21	21	21	20
T_{Av}	19.3	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20.6	20
T_4	23	24	23	24	24	24	24	24	24	24	24	23
T_5	20	21	22	22	22	22	22	22	22	22	22	22
T_{Av}	21.3	23	22.5	23	23	23	23	23	23	23	23	22.5
T_6	8	9	9	9	9	9	9	9	9	9	9	8
T_7	21	22	22	23	23	23	23	23	23	23	23	23
T_8	22	23	23	23	23	23	23	23	23	23	23	23
T_9	21	22	22	22	22	23	23	23	22	23	22	22
T_{Av}	21.3	22.3	22.3	22.6	22.6	23	23	23	22.6	23	22.6	22.6
T_{10}	16	17	17	17	17	17	17	17	17	17	17	18

Heat Flux Plates

1	6.59	6.48	*	6.69	6.78	6.91	6.58	6.98	7.05	6.72	6.62	7.02
2	3.43	3.83	*	3.92	4.03	4.06	4.16	4.09	4.03	4.03	4.05	4.02

Observations:

THREE LAYERS/NEW CURTAIN TWO REFLECTIVE SIDES FACING IN & ONE FACING OUT

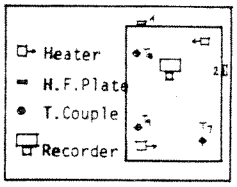


Chart #	☒ Clear	☒ No Wind	Energy Final	9.3
31	☐ Partial Cover	☐ Modrate Wind	Previous	2657.5
	☐ Overcast	☐ Windy	Net	1.8

Day/Night

Date May 8, 1980

Humidity 60%-65%

Temperature

	0	10	20	30	40	50	60	70
T_1	12	12	12	12	12	11	11	11
T_2	12	12	12	12	12	12	12	11
T_3	12	12	12	12	12	12	11	11
T_{Av}	12	12	12	12	12	11.6	11.3	11
T_4	14	13	13	12	12	12	12	11
T_5	13	13	12	12	11	11	11	11
T_{Av}	13.5	13	12.5	12	11.5	11.5	11.5	11
T_6	7	7	6	6	7	7	7	7
T_7	23	21	21	21	21	21	21	20
T_8	27	24	23	21	21	22	22	21
T_9	28	22	22	21	21	22	21	20
T_{Av}	26	22.3	22	21	21	21.6	21.3	20.3
T_{10}	18	18	19	19	19	19	19	19

Heat Flux Plates

1	4.80	.95	.77	.67	1.03	1.30	.76	.82
2	2.52	1.43	1.20	1.07	1.43	1.84	1.18	1.15

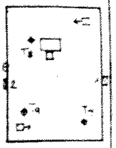
Observations: Special test to determine the thermal gradient of the vertical curtain. The side along the adjoining greenhouse looses 30% less heat than the other three sides.

The heat was not turned on for the first 30 min.

THREE LAYERS/NEW CURTAIN TWO REFLECTIVE SIDES FACING IN & ONE FACING OUT

Chart # 32	☐ Clear	☐ No Wind	Energy Final	3184.9	Day/Night
	☐ Partial Cover	☒ Moderate Wind	Previous	3182.5	Date May 13, 1980
	☒ Overcast	☐ Windy	Net	2.4	Humidity 65%

☐→ Heater
▬ H.F.Plate
● T.Couple
Recorder



Temperature

	0	10	20	30	40	50
T_1	17	18	18	18	18	18
T_2	18	18	18	18	18	18
T_3	18	18	18	18	18	18
T_{Av}	17.6	18	18	18	18	18
T_4	19	19	19	19	19	18
T_5	18	18	18	18	18	18
T_{Av}	18.5	18.5	18.5	18.5	18.5	18
T_6	11	11	11	11	11	11
T_7	27	27	26	27	27	26
T_8	24	26	26	28	27	27
T_9	24	26	26	27	26	25
T_{Av}	25	26.3	26	27.3	26.6	26
T_{10}	22	22	22	23	23	23

Heat Flux Plates

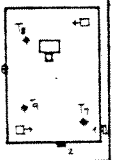
1	2.62	1.24	.94	3.52	1.19	.95
2	1.89	.88	.64	2.13	.79	.59

Observations: Special test to determine the thermal gradient of the vertical curtain.

THREE LAYERS/NEW CURTAIN TWO REFLECTIVE SIDES FACING IN & ONE FACING OUT

Chart # 33	☐ Clear	☐ No Wind	Energy Final	31867	Day/Night
	☐ Partial Cover	☒ Moderate Wind	Previous	31845	Date May 6 1980
	☒ Overcast	☐ Windy	Net	22	Humidity 65%

☐→ **Heater**
▬ **H.F.Plate**
● **T.Couple**
Recorder



Temperature

	0	10	20	30	40	50
T_1	17	18	18	18	18	18
T_2	18	18	18	18	18	18
T_3	18	18	18	18	18	18
T_{Av}	17.6	18.0	18.0	18.0	18.0	18.0
T_4	18	18	19	18	18	18
T_5	18	18	18	18	18	18
T_{Av}	18.0	18.0	18.5	18.0	18.0	18.0
T_6	11	11	11	11	11	10
T_7	28	29	30	29	29	30
T_8	27	29	29	28	29	28
T_9	26	28	30	28	26	29
T_{Av}	27.0	28.6	29.6	28.6	28.0	29.0
T_{10}	23	23	23	23	23	23

Heat Flux Plates

1	3.35	3.41	1.98	1.38	2.08	3.02
2	3.63	3.32	1.45	.96	1.18	2.90

Observations: Special test conducted to determine the gradiant (temperature) along the vertical curtain, in both vertical as well as horizontal directions.

THREE LAYERS/NEW CURTAIN TWO REFLECTIVE SIDES IN & ONE FACING OUT

☐→ Heater
▬ H.F.Plate
● T.Couple
☐ Recorder

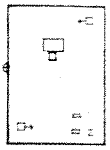


Chart # 34	☐ Clear ☒ No Wind	Energy Final	3386.8	Day/Night
	☐ Partial Cover ☐ Modrate Wind	Previous	3379	Date May 18, 1980
	☒ Overcast (rain) ☐ Windy	Net	7.8	Humidity 60%

Temperature

	0	10	20	30	40	50	60	10	20	30	40	50	2								
T_1	19	18	20	19	18	18	20	20	20	18	18	19	19								
T_2	16	17	17	17	17	17	17	17	18	17	17	17	17								
T_3	16	17	17	17	17	17	18	18	18	18	17	17	17								
T_{Av}																					
T_4	17	17	18	18	18	18	18	18	18	18	18	18	18								
T_5	17	17	18	17	17	17	18	18	18	18	18	18	17								
T_{Av}																					
T_6	11	11	12	11	12	12	12	12	12	12	12	12	12								
T_7	28	30	34	31	29	31	33	33	33	31	30	32	33								
T_8	28	33	35	29	27	31	32	33	32	27	29	31	32								
T_9	27	28	32	28	26	29	30	30	30	28	27	29	30								
T_{Av}																					
T_{10}	20	20	21	20	21	21	21	22	23	23	24	23	23								

Heat Flux Plates

1	1.07	1.14	1.37	.82	.51	1.13	1.23	1.14	1.27	.56	.80	1.15	1.18								
2	.94	1.50	1.63	1.12	1.01	1.12	1.18	1.25	1.01	1.28	1.52	1.04	1.37								

Observations: Special test to determine the gradient (thermal) of the horizontal curtain. Within the curtain T_9 was located in contact with the heat flux plate #1, T_7 was placed 2cm away from the heat flux plate, T_8 was kept 10cm away from the heat flux plate; outside the curtain T_1 was kept in contact with the hfp. and T_5 was placed 10cm away from the hfp.

ADDENDUM IV

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Joel C. Simpkins, David R. Mears, William J. Roberts. Reducing Heat Losses in Polyethylene Covered Greenhouses. ASAE Transactions. Paper No. 75-4022.

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ADDENDUM V

MANUFACTURERS

GREENHOUSE MANUFACTURERS/SUPPLIERS

Ickes-Braun
Glasshouses of Canada, Ltd.
90 Bartlett Road
P.O. Box 2000
Beamsville, Ont. LOR 1BO

Irrigation St. Thomas, Inc.
1044 rue Principle
St. Thomas de Joliette
Quebec J0K 3L0

Lord and Burnham Co. Ltd.
4422 Graham Drive
Pierrefonds, Quebec H9H 2C2

National Greenhouse Co.
P.O. Box 100/Pana.
111 62557. U.S.A.

Solagro Ltée
52, Victor Léger
Valleyfield, Qué. J6T 3J1

Stuppy Inc.
120 East 12th Ave.
North Kansas City
MO 64116 U.S.A.

Vary Greenhouses Inc.
Canadian Greenhouses
Box 5000
Beamsville, Ont. LOR 1BO

Vegetable Factory Greenhouses
100 Court Street
Cofiagne, L.I.
N.Y. 11726 U.S.A.

GREENHOUSE INSULATION MATERIAL AND SUPPORT SYSTEM SUPPLIERS

Duracote Corporation
350 North Diamond Street
Ravenna, Ohio 44266
U.S.A.

Greenshield Systems
Division of Automatic Devices Co.
2121 South Twelfth Street
Allentown, PA 18103
U.S.A.

Roll-Out Insulation Systems, Inc.
P.O. Box 31
East Aurora, New York 14052
U.S.A.

Simtrac Inc.
8243 N. Christiana Ave.
Skokie, Ill. 60076
U.S.A.

Stauffer Chemical Co.
Plastics Division
One Metroplaza
Edison, N.J. 08817
U.S.A.

Stuppy Inc.
120 East 12th Ave.
North Kansas City, MO 64116
U.S.A.

Wadsworth Control Systems
A Division of the Roper Corporation
5541 Marshall Street
Arvada, Colorado 80002
U.S.A.

DOMESTIC THERMAL SCREEN MFGS/SUPPLIERS

Appropriate Technology Corporation
P.O. Box 975
Brattleboro
Vt. 05301 U.S.A.

Centre for Community Technology
University of Wisconsin Extension Service
1121 University Ave.
Madison, Wis. 53715 U.S.A.

Drape Masters
266 Prospect Ave.
Hartford
CT. 06106 U.S.A.

Homesworth Corporation
34 Cumberland St.
Brunswick
ME. 04011 U.S.A.

Insulating Shade Company, Inc.
P.O. Box 282
Branford, CT 06405 U.S.A.

Insul Shutters
110 N. Seventh Street
Silt, Col. 81652 U.S.A.

Solar Energy Components Inc.
212 Welsh-pool Road
Lionville, PA 19353 U.S.A.

Sun Flake
625 Goddard Ave.
P.O. Box 676
Ignacio, Colo. 81137 U.S.A.

Thermal Technology Corporation
P.O. Box 130
Snowman, Colorado 81654 U.S.A.