ENERGY CONSERVATION IN COMMERICAL GREENHOUSES OPERATED IN COLD CLIMATES

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ABSTRACT

The primary objective of this paper is to show the distribution of heat losses in prairie commercial greenhouses of various constructions and to suggest and test methods of energy saving. Seventy five percent of the total heat loss is through the roof of a glass greenhouse. This can be significantly reduced by adding an extra layer of polyethylene preferably in the area where lower light levels can be tolerated.

1. INTRODUCTION

Four typical types of commercial greenhouses located in Saskatoon and Regina, Saskatchewan were investigated. Their various shapes, sizes, types of cover, crops, and heating systems are tabulated in Table 1. From the values shown in the table, the major component of the heat loss was from the roof which was an average of 75 percent for the glass greenhouses and 80 percent for the double polyethylene of the total heating load of the greenhouses. Therefore, increasing the thermal resistance of the roof offers the greatest potential for reducing the heating cost if it can be done without significantly reducing the light transmission.

In single glass greenhouses (A and B in Table 1) an additional layer of polyethylene significantly reduces the heat loss through the roof because of the doubling of the thermal resistance and lowered infiltration rate. The light transmission is reduced by about 10 percent and, depending upon the crop and its growing period, production can be lowered up to 10 percent. If the reduced value of the crop plus the yearly charge for the installation of the poly is less than the yearly saving in heating costs, this energy saving technique is justified. Experiments were undertaken to determine initial costs, plant production and energy savings in the two glass greenhouses. Only the energy savings are discussed in this paper. Beside the saving technique of putting an additional layer of polyethylene, the second means of reducing heating costs is to install an extra night retractable curtain inside the inflated polyethylene envelope.

The indoor and outdoor temperatures and natural gas consumption during the night (to eliminate the solar radiation effect) were recorded daily for the purpose of obtaining the energy savings of these two methods compared to the original single glass greenhouses. The energy savings of the thermal curtain were determined by closing the curtain on alternate nights and comparing the night time gas consumptions.

2. THE ENERGY SAVINGS OF ADDING LAYERS OF POLYETHYLENE TO SINGLE GLASS GREENHOUSES

The glass covered single span greenhouse, A in Table 2 and as shown in Figure 1 had one layer of polyethylene attached underneath the glass. For the type B an air-inflated double layer polyethylene was installed over glass to avoid the construction barriers of the greenhouse. Both systems in type A and B were difficult to install. The existence of pipe and posts

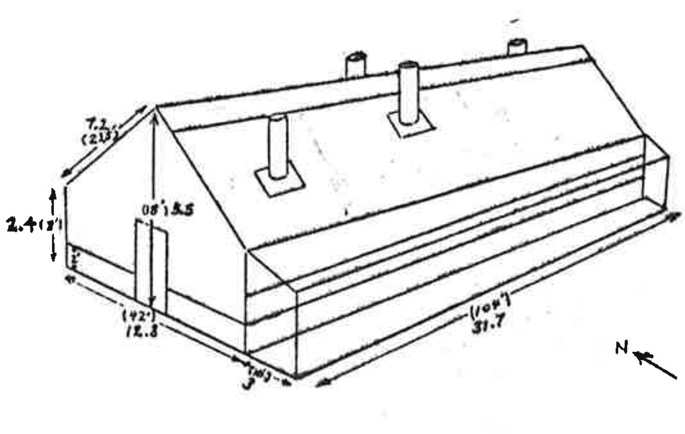


FIG. 1 OUTLINE OF THE TYPE A SINGLE SPAN GREENHOUSE

TABLE 1. COMMERCIAL GREENHOUSES

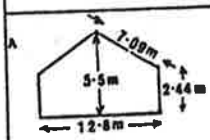
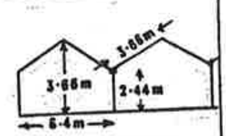
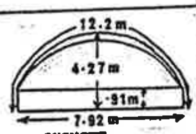
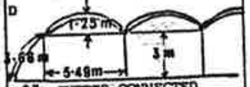
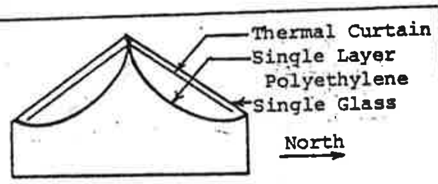
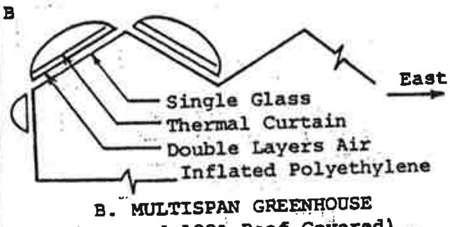
SHAPE	SIZE L-LENGTH	COVERS	PRODUCTION	HEATING SYSTEM	DISTRIBUTION OF HEAT LOSSES % of Total: ROOF CALC(KW)	ROOF %	ENDS & FLOOR CALC(KW)	ENDS & FLOOR %	INFILTRATION & MISC. AC/hr	INFILTRATION & MISC. %
A  SINGLE GREENHOUSE (Truss Supported)	L = 31.4m Floor Area = 401.8m^2 Volume = 1347 m^3	Single Glass (Good construction & maintenance)	1) Bedding Plants (February to June)	Gas-Fired Unit Heaters (At roof without ducts)	230	73	69	22	.5 AC/hr (Measured with tracer gas)	5
B  MULTISPAN GREENHOUSE (5 Unit Houses)	L = 36.6m Floor Area = 1172m^2 Volume = 3780m^3	Single Glass (Poor maintenance)	1) Bedding Plants 2) Potting Plants 3) Cutflowers	Gas-Fired Unit Heaters (At roof level without ducts)	780	74	139	13	2 AC/hr (Measured with tracer gas)	13
C  QUONSET (14 Bays)	13 Houses L = 29.3m 1 House L = 14.6m Floor Area = 3132m^2 Volume = 9092m^3	Double Layers Inflated Polyethylene	1) Bedding Plants 2) Tomatoes 3) Cucumbers	Gas-Fired Unit Heaters (Ducts at Roof level)	1160	82	65	5	1 AC/hr (Measured with tracer gas)	13
D  ·2·7· GUTTER-CONNECTED (7 Bays)	7 Bays L = 59.13m Floor Area = 2478m^2 Volume = 9416m^3	Double Layers Inflated Polyethylene	1) Tomatoes 2) Cucumbers	Waste Heat (Hot Water) Ducts at Floor Level	770	85	82	9	.29 AC/hr (Measured with tracer gas)	6

TABLE 2. MODIFIED GREENHOUSES

CALC.-Calculated Value
% -% of Total

SHAPE	TYPE OF COVERS	DISTRIBUTION OF HEAT LOSSES: ROOF CALC. (KW)	ROOF %	ENDS & FLOOR CALC. (KW)	ENDS & FLOOR %	INFILTRATION MEASURED (KW)	INFILTRATION %	TOTAL SAVING %: EXPERIMENT	TOTAL SAVING %: THEOR
A  A. SINGLE SPAN GREENHOUSE (65% Roof Covered with Poly & Curtain)	Single Layer Poly.	117	61	69	36	6	4	36	38
	Poly. Plus Curtain	65	46	69	49	6	5	50	55
	Difference Between Poly. and Poly+Curtain	52	44	0	0	0	0	6	27
B  B. MULTISPAN GREENHOUSE (Assumed 100% Roof Covered)	Double Layers Poly.	324	70	105	23	34	7	50	56
	Poly. Plus Curtain	256	66	96	25	34	8	50-60	63
	Difference Between Poly. and Poly+Curtain	68	21	9	8	0	0	12	17

inside the greenhouse made the type A system very difficult to place polyethylene underneath the glass and hard to seal the edges of the polyethylene. The installation of type B greenhouse polyethylene was also time consuming because of the wind and narrow working spaces on the roof.

An additional cover of polyethylene over a single glass can reduce the infiltration heat loss especially with old, wooden frame, single glass greenhouses.In Table 3, the infiltration rate of both type A and B greenhouses are reduced up to 1/2 of the original air change per hour after the addition of polyethylene. However, the major saving is from the increased thermal resistance of the inflated air space between the layer of polyethylene and the glass.

The average night time gas consumption for type A greenhouse was plotted against the indoor and outdoor temperature difference in Fig. 3. From the graph, the saving of adding an extra layer of polyethylene underneath glass was found to be 26 percent with 2/3 of the roof covered by single layer of polyethylene. The reason of covering only 2/3 of the roof was because of the existance of the heater units at roof level made it very difficult to install polyethylene for the rest of the roof. For covering the north roof, side walls and both ends of an East-West orientation greenhouse with an additional layer of polyethylene, the saving was found to be 36 percent. This was obtained with very good light levels because of the omission of the additional layer of polyethylene on the South facing roof which contributed the major portion of the light. By extrapolation, if the whole roof was covered, a 50 percent saving would be expected.

For type B greenhouse which was shown in Figure 2, a saving of 29 percent compared to the winter of 1981-82 was found from October 1982 to April 1983 by adding air-inflated double layer polyethylene over the west and east units' glass which occupied 30 percent of the entire greenhouse roof. The test was repeated in 1983-84 with 1/3 of the single glass roof covered with double layer of polyethylene. The energy savings was found to be 27 percent compared to the winter of 1981-82. The fuel saving would be 60 percent if the whole roof was covered.All the above saving values were obtained by the analysis of the gas consumption bills for the past four years. All the data are shown in Table 4. Note that the average global radiation and wind velocity are essentially equal for the three years.

An alternative to applying polyethylene over the entire roof is to cover portions of the greenhouse in which light tolerated plants can be grown and omitting it in sections where higher lighting levels are required so that both purposes of energy conservation and no interfere on plants growth can be achieved by employing the partly covered roof method.

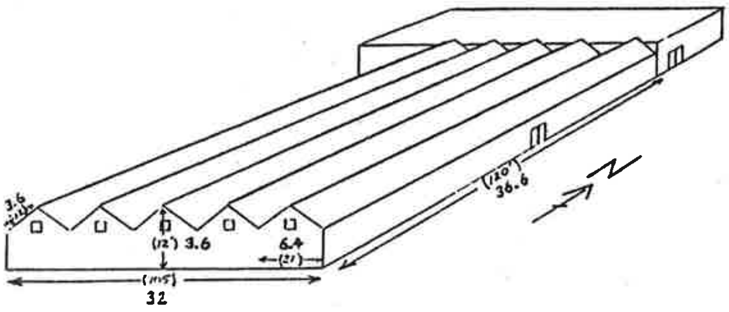


FIG. 2 THE TYPE B GUTTER-CONNECTED GREENHOUSE

3. THE ENERGY SAVINGS OF THE RETRACTABLE CURTAIN

In previous investigations(1, 2, 3), a retractable curtain installed inside at the mid-height of the greenhouse has demonstrated energy savings up to 50 percent. However, a serious condensation and frosting problem is inevitable in cold climates when employing these internal thermal curtain. The warm, humid air circulates past imperfect edge seals of the curtain into the cold space above and the water vapour condenses on the roof and falls on the curtain. In mild climates, pools of water collected on the top of the curtain and holes are provided to drain the water. For cold climates, frost forms on the glass and when the curtain is opened in the morning, the heat from the sun and heating system melts the ice, and it falls damaging the plants.

To overcome this difficulty in cold climates, a moveable reflective insulation may be installed between the inflatable polyethylene and the greenhouse glass surface (Table 2). Outdoor air is used for inflation, therefore, there is no condensation in the inflated space. There is very little cold air entering the inflated space providing that the edges of the polyethylene are well sealed.

In this study, the type A single glass greenhouse was installed with night retractable reflective curtains placed underneath the glass and enclosed internally by a single layer of polyethylene as illustrated in Table 2. The disadvantage of this system is the difficulties in installing the curtains because of the pipes and the posts inside the greenhouse. To avoid these construction barriers, in the type B greenhouse, aluminized retractable curtains were installed outside the glass and enclosed by the air-inflated double polyethylene as shown in Table 2. Both the systems in type A and B were labor intensive.

The additional saving contributed by the curtains in type A greenhouse was limited to 6

FIG. 3 THE NIGHT TIME ENERGY CONSUMPTION FOR TYPE A GREENHOUSE

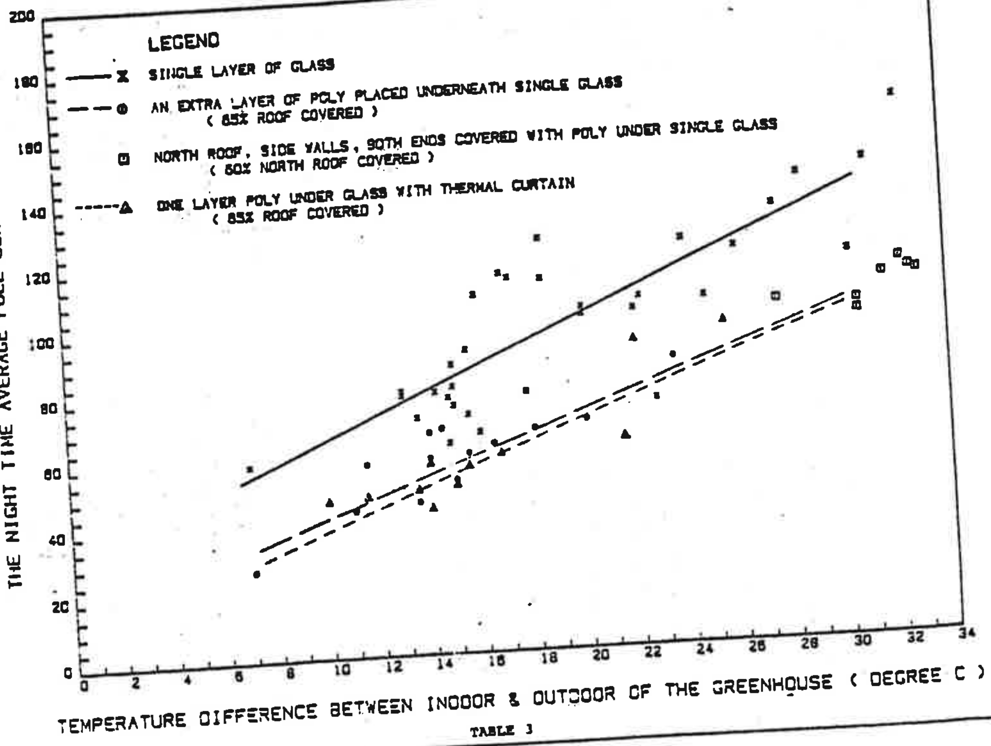


TABLE 3

INFILTRATION LOSSES (AIR CHANGE PER HOUR)

	A. Single	B. Multispan	C. Quonset	D. Gutter-Connected	Quonset (Experimental, Fibreglass Cover 7.9m wide, 12.8m long, 4m height
Original	0.5	2			1
Modified	.25	.5	1.2	.26	.7

TABLE 4. THE ENERGY CONSUMPTION OF TYPE B

MONTH-DATE	GAS USAGE (m^3)	AMOUNT CHARGED ($ PER m^3)	TOTAL CHARGED ON BILLS ($)	TOTAL CHARGED AT $0.125/$m^3$	MONTHLY MEAN TEMP. (°C)	TOTAL GLOBAL RADIATION (LANGLEYS)	MEAN WIND SPEED (km/hr)	DEGREE-DAYS (Temp. Diff. Between Indoor & Outdoor)	INDOOR TEMP. SET AT 15.6°C $ Per Degree-Days
Sept 24 - Oct 26 1981	16217	0.098	1604.27	2027.13	3.0	4728	16.0	340.2	5.96
Nov 17	17300	0.098	1709.10	2162.5	0.5	2750	12.7	319.7	6.76
Dec 22	24747	0.098	2429.97	3093.38	-13.0	2483	12.8	825.5	3.75
1982 Jan 22	25308	0.098	2484.28	3163.5	-26.5	3479	12.5	1083.6	2.92
Feb 18	14926	0.112	1579.38	1865.75	-16.0	5225	13.7	947.7	2.78
Mar 22	18551	0.112	2085.82	2318.89	- 8.0	9071	15.6	835.2	2.87
Apr 21	15744	0.112	1771.15	1968.0	2.0	12593	15.9	498.0	3.95
THE TEST PERIOD 1981-82 AVERAGE VALUES:						5761	14.1	692.0	4.14
Sept 22 - Oct 26 1982	10409	0.113	1173.10	1301.13	5.5	6138	13.3	299.4	4.34
Nov 23	12483	0.113	1405.59	1560.38	-10.0	3663	12.2	639.3	2.44
Dec 23	28267	0.113	3174.98	3533.38	-11.7	1945	12.7	807.1	4.31
1983 Jan 21	15669	0.113	1762.74	1958.63	-13.0	2775	11.7	819.0	2.39
Feb 22	10467	0.113	1179.60	1304.86	-10.0	4137	14.4	849.2	1.53
Mar 21	13063	0.113	1470.61	1632.88	- 7.0	8460	16.5	628.2	2.59
Apr 19	11275	0.113	1270.18	1409.38	3.0	12921	15.6	465.4	3.02
AVERAGE VALUES: % DIFFERENCE COMPARE WITH THE TEST PERIOD OF 1981-82: (30% ROOF COVERED)						5720 0.7%	13.8 2%	644.0 6.9%	2.94 29%
Sept 15 - Oct 18 1983	7733	0.125	965.95	965.95	5.3	6009	12.3	269.4	3.58
Nov 16	12090	0.125	1506.22	1506.22	- 2.9	2353	12.9	429.9	3.50
Dec 22	29622	0.125	3608.19	3608.19	-22.8	2541	12.0	1103.8	3.33
1984 Jan 24	20873	0.125	2593.31	2593.31	-12.1	2094	14.3	933.6	2.77
Feb 21	10195	0.125	1271.24	1271.24	- 3.9	5018	13.4	603.4	2.10
Mar 21	12178	0.125	1517.13	1517.13	- 5.5	7187	12.8	599.1	2.53
Apr 19	10866	0.125	1354.44	1354.44	7.4	12081	14.8	387.9	3.49
AVERAGE VALUES: % DIFFERENCE COMPARE WITH THE TEST PERIOD OF 1981-82: (33% ROOF COVERED)						5329 7%	13.22 6%	618.3 10%	3.03 27%

TABLE 5. THE ENERGY SAVING OF THE THERMAL CURTAIN IN TYPE B GREENHOUSE

THERMAL CURTAIN CLOSED

Date	Indoor & Outdoor Temperature Difference (°C)	Gas Consumption (m^3)	Total Degree Hours	Energy Consumption Per Degree (KW/°K)
(1982)				
Dec 9	33.94	77.31	526.14	1.52
Dec 11	26.28	89.49	446.72	2.07
Dec 13	27.33	62.30	435.15	1.48
Dec 15	23.78	69.10	384.49	1.86
Dec 17	25.78	74.20	420.95	1.82
Dec 19	24.61	70.52	393.78	1.85
(1983)				
Jan 4	25.60	71.37	460.80	1.60
Jan 7	26.28	80.43	420.48	2.26
Jan 12	24.44	83.83	421.59	2.06
Jan 14	27.17	108.47	421.14	2.67
Jan 17	27.39	87.23	438.22	2.06
Jan 19	26.39	82.13	395.83	2.15
Jan 21	24.17	74.20	401.89	1.91
Jan 24	46.00	96.29	759.00	1.31
Mar 3	16.22	45.14	239.25	1.95
Mar 8	23.06	61.17	340.14	1.86
Mar 10	14.71	43.87	220.65	2.06
Mar 14	26.99	62.87	416.19	1.56
Mar 15	18.33	53.81	276.42	2.01
Mar 17	30.01	89.49	448.65	2.06

Average Gas Consumption Per Degree = 1.92 KW/°K (Curtain Closed)

THERMAL CURTAIN OPENED

Date	Indoor & Outdoor Temperature Difference (°C)	Gas Consumption (m^3)	Total Degree Hours	Energy Consumption Per Degree (KW/°K)
(1982)				
Dec 10	38.22	98.27	640.22	1.59
Dec 12	24.61	93.46	389.59	2.48
Dec 14	28.22	85.24	437.44	2.02
Dec 16	18.06	58.62	288.96	2.10
(1983)				
Jan 5	26.67	93.46	433.33	2.23
Jan 6	30.33	97.14	480.12	2.09
Jan 11	25.89	91.47	399.21	2.37
Jan 13	24.28	91.47	376.31	2.52
Jan 18	32.72	89.77	490.80	1.89
Jan 20	26.00	83.54	390.00	2.22
Mar 1	22.93	71.93	343.95	2.16
Mar 2	20.69	77.60	329.38	2.44
Mar 7	25.75	84.96	418.44	2.10
Mar 9	20.64	73.92	314.76	2.43
Mar 16	26.99	82.41	402.69	2.12
Mar 18	30.26	89.49	453.97	2.04

Average Gas Consumption Per Degree = 2.18 KW/°K (Curtain Opened)

The Energy Saving in Percentage When Curtain Closed = 12%

percent because of the air circulated through the unsealed edges of the curtains which were so difficult to seal. From Table 5, the saving of the curtains in type B greenhouse was found to be 12 percent because of the internal glass absorbed the long wave radiation so that the radiation properties of the insulation were not effective.

4. THE TEMPERATURE GRADIENT OF THE GREENHOUSE

The vertical air temperature variation of the greenhouses were also investigated. In all test greenhouses, the heating was above the benches and the average temperature from the floor to the benches was found to have a variation of 2 to 4 degree C and, from the benches to the roof, the difference was found to be as high as 11 degree C. The higher temperature at roof level significantly increases the indoor and outdoor temperature difference and hence the heat loss. Placing the heat distributing element at the floor is a low cost energy saving technique to reduce the heat loss due to the large temperature gradient. Another method is to use ceiling fans at roof level for more evenly heat distribution inside the greenhouse. The type B greenhouse was equipped with ceiling fans and this decreased the temperature difference at roof and kept warmer temperatures at the plant level which implied a better yield of products and less heat loss.

5. THE INFILTRATION PERFORMANCE OF THE GREENHOUSES

The infiltration losses of various greenhouses were investigated by applying the gas decay method using nitrous oxide as the tracer gas. The experimental results were used to calculate the infiltration losses in Table 1 and are compared after modification in Table 3. From the percentage of total heat losses in Table 1, the average infiltration losses were found to be about 10 percent which is small compared with the roof heat loss in the commercial greenhouses.

6. CONCLUSIONS

1) An effective means of reducing heating costs in single glass greenhouses is the addition of polyethylene cover on roof.

2) For better light transmission and crop production, a greenhouse can be partly covered with single layer of polyethylene over glass on both ends andthe north side of the roof in order to provide good light intensity for growing while still saving energy.

3) An alternative to applying polyethylene over the entire roof is to cover portion of the greenhouse in which light tolerance plants can be grown and omitting it in sections where higher lighting levels are required.

4) The higher labor cost and the difficulties in installation make the reflective curtains in sealed elements uneconomic.

5) The infiltration heat loss is very low compared to the heat losses through the roof, therefore, extensive sealing around the greenhouses is not worthwhile.

6) A heating system or air distribution system that reduced the temperature gradient from floor to ceiling can be an effective means of reducing energy losses in commercial greenhouses.

7. ACKNOWLEDGEMENT

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8. REFERENCES

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