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GREENHOUSE HEAT CONSERVATION: COVERS VS. ATMOSPHERIC CONDITIONS DURING A FIVE-YEAR PERIOD

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The 1973 fuel crisis initiated a wave of predictions, comparisons and in some instances, poor documentation of greenhouse fuel conserving results and practices among growers and researchers around the world. It has been difficult for the purchaser of heat conserving equipment or instigator of fuel reducing practices, to digest the mass of information, pro and con, that has been presented the past nine years. However, no matter how ambiguous the information, the greenhouse operator has come to realize he/she must give fuel conserving measures top billing on their priority list, in order to survive.

Research Results Differ

The degree of variation in fuel conserving data can be demonstrated in the work accomplished at Colo. State Univ. in the mid 1970's. Tristan (1977) reported a 23 percent fuel savings by using Foylon 2000/P as a loosely fit thermal (heat) blanket within a greenhouse. The data was obtained by opening and closing the blankets in a single greenhouse, on alternate nights, throughout an 86 day period from December 1974 and March 1, 1975. Hay (1978) using the same greenhouse, reported that tight fitting Monsanto 602 Polyethylene, provided 26 percent fuel savings. He compared 70 nights using the blanket system to 112 nights without it from November 1976 and March 1977.

A much greater difference in fuel savings was obtained by Pennsylvania State University researchers (White et al., 1976). They obtained 55 percent savings in an experiment conducted during the same time period as the Tristan study and using similar methods and materials. However, their study only involved five nights of data for their initial investigation.

Studies conducted at the Wageningen Holland Research Center in 1977-78, using thermal blankets lead to a range of predictions on blanket efficiency. They were using a cheesecloth-like material and based on their experiences, suggested in a personal interview, that a 20 to 30 percent fuel savings is all that could ever be expected from any thermal blanket system.

The methods of evaluating fuel conserving techniques or systems are often less than desirable. In all four of the previously described experiments, more realistic data would have been obtained if each house could have been replicated two or three times — but funds prohibit such facilities. Secondly, a better "picture" of the results could have been obtained if the atmospheric conditions, prevailing during each experiment, could have been exactly alike geographically and from year to year.

Atmospheric Conditions Vary

Temperature. It is difficult to compare or predict the influence of greenhouse energy conserving equipment or systems from one year to the next or even week to week due to atmospheric conditions within a geographical location.

Temperatures alone can often be confusing and definitely unpredictable. When six past heating seasons were compared (Table 1), based on maximum and minimum mean temperatures, some definite trends were noted. First, the months of January and February were definitely the coldest in the Fort Collins, Colorado area. Second, March never had temperatures below 0°F. The 1978-79 heating season was one of the coldest in years and the 1980-81, the warmest. Even though it isn't documented or apparent in the table, the 1979-80 season produced almost a total of 10 ft of snow and the following season, hardly two feet.

Wind velocities in the Fort Collins geographical area cannot be predicted. The coldest air temperatures, ex-

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Table 1. Monthly maximum and minimum air temperature means of four winter months in Fort Collins, Colorado (105°-4' W long. and 40°-35'N lat., elev. 1550 M) from December 1975 through March 1981. (Courtesy Colo. Climate Center, Colo. State Univ., Ft. Collins, CO 80523).

FORT COLLINS

	December		January		February		March		Average[z]	
	$\bar{T}$max	$\bar{T}$min	$\bar{T}$max	$\bar{T}$min	$\bar{T}$max	$\bar{T}$min	$\bar{T}$max	$\bar{T}$min	$\bar{T}$max	$\bar{T}$min
1975-76	45.9	19.6 (1)	42.4	14.2 (5)	50.8	23.2 (1)	51.8	22.1 (0)	47.7	19.8 (7)
1976-77	48.9	17.5 (1)	40.4	10.3 (3)	50.6	22.1 (0)	53.8	24.2 (0)	48.4	18.5 (4)
1977-78	46.8	21.0 (1)	35.0	12.3 (2)	37.1	18.7 (1)	56.8	28.2 (0)	43.9	20.1 (4)
1978-79	35.7	9.5 (6)	28.8	4.9 (12)	42.5	13.2 (6)	52.8	27.9 (0)	40.0	13.9 (24)
1979-80	45.3	17.9 (2)	35.8	11.5 (6)	42.7	17.1 (2)	46.9	23.8 (0)	42.7	17.6 (10)
1980-81	53.1	24.5 (0)	48.0	18.2 (0)	50.1	18.9 (2)	52.1	28.5 (0)	50.8	22.5 (2)
AVERAGE[y]	46.0	18.3 (11)	38.4	11.9 (28)	45.5	18.9 (12)	52.4	25.8 (0)		

(   ) = Total number of days with Tmin ≤ 0°F.

[z] Averages of five monthly means.

[y] Average of six year column means.

cluding chill factors, are associated with almost "still" conditions. In 1952, a -42°F was experienced, but no air movement recorded. On January 11, 1972, greenhouse damaging wind velocities reached 110 mph with a temperature of 50°F. Similar conditions were experienced again in January 1981.

Both Tristan (1977) and Sherry (1978) reported that wind did influence the greenhouse fuel requirements at low velocities and heat conserving programs could reduce its influence substantially.

Solar radiation. The Rocky Mountain area of Colorado is definitely part of the "sun belt". There are more than 300 days with sunshine and the insulation during winter months is exceptional. The total solar radiant energy received from year to year during a four month period (Table 2) did not vary more than 11 percent overall and a maximum of eight percent from year to year. The "greenhouse effect" and fuel requirements for heating during daylight hours are therefore associated with solar radiant flux, greenhouse covering, outside temperature, and to a lesser degree, the various other parameters of atmospheric conditions. Experience has shown that during November, December, or January, the radiant flux density received in a greenhouse on a cloudless day, can retain the desired plant temperatures as long as the outside temperatures do not go below -3°C (25°F).

Table 2. Total gram calories received in Fort Collins, CO during four winter months from 1975-1981.

Year	December	January	February	March	Four Month Total
1975-76	5576	5291	7949	11,690	30,506
76-77	5721	6561	7705	12,271	32,258
77-78	5241	5742	6464	12,274	29,721
78-79	5110	6074	7988	9,824	28,996
79-80	5481	5706	7290	10,372	28,849
80-81	4552	6210	4933*	10,337	26,032
Six Year Total	31,681	35,584	42,329	66,768	

*Equipment malfunction, 19 days data

It should be noted however, a cloud cover can and does have an equalizing effect on the transmitting characteristics of any greenhouse cover (Hanan et al., 1978). During periods of total overcast, there is little or no difference in the radiant flux density received under any of the commercially available greenhouse covers. Another aspect that limits solar energy received in the greenhouse in winter, especially in more northern latitudes, is the snow load that remains on the greenhouse roof. When outside sub-zero temperatures on cloudless or semicloudless days occur, a "skiff" or several inches of snow often remains on a roof, reducing insulation. Such a condition is the major fault of double layered covers.

Condensate present on the inside of a cover and/or between the layers of a double cover will also reduce solar energy received in a greenhouse. The colder the outside temperatures, the more the condensate forms.

Greenhouse Covers

In 1976 Sherry (1978) constructed four quonset greenhouses, Figure 1, identical in size, environmental controls and data collecting equipment. Each house 6.1 m × 14.6 m (20 × 48 ft), covered 89.2 m² (960 ft²) and had a roof

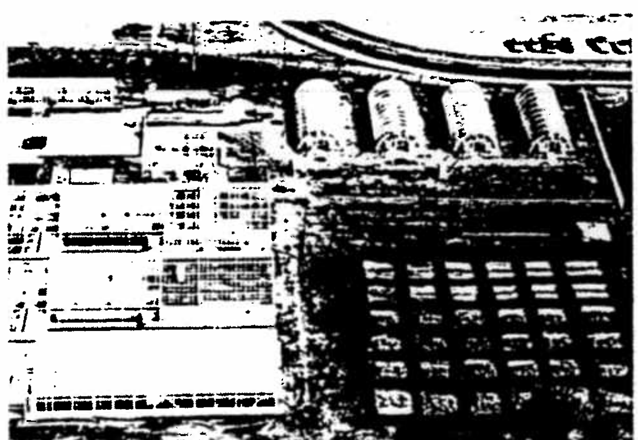

Fig. 1. Colorado State University, W.D. Holley Plant Environmental Research Center greenhouse complex. The four identically constructed quonsets were used in the 1976-81 fuel conservation studies

surface of 124.1 m² (1344 ft²). The ends were identical, covered with insulation board on the north and FRP panels on the south.

The structures have been used for solar transmission characteristics, influence of fuel requirements and crop responses due to the covers (Table 3).

1976-77: The original covers, included: new 5 oz. corrugated fiberglass reinforced plastic panels, standard grade, (new FRP); a single layer of Monsento 602 polyethylene inflated by air (Dbl poly) and eight year old well weathered standard FRP panels (old FRP). The same covers were used in a second seasons evaluations (1977-78). The FRP covered structure was used as the "base" on control house.
1978-79: The single poly cover was replaced with 5 oz Tedlar coated FRP panels (base). The double poly cover was left on for the third year.
1979-80: The original standard FRP cover was becoming weathered, "fiber bloom" occurring and yellowed with reduced light transmission characteristics. New "602" was installed and the 10 year old FRP cover was replaced with 6mm Qualex, a double wall polycarbonate.
1980-81: The old FRP covered house was not used in the evaluation. The other three retained the same coverings as the previous year.

Fuel Consumption

All greenhouses were heated to temperatures of 10-11°C (50-52°F) night and 15-16°C (60-62°F) day for the evaluation of cool crops from 1976 through 1981.

The various covers, Table 3 and Figure 2, definitely influenced the greenhouse fuel consumption within a heating season and from one year to another. One will have to compare Tables 1 and 2 with Table 3 in order to invision seasonal fuel consumption trends. As an example, the 1976-77 and 1980-81 heating seasons were the warmest and the "base" houses used less fuel during the four month period than in the other seasons. The most fuel was used by a "base" house during the 1979-80 season, yet the outside temperatures were lower the previous year. Even though the solar radiation received the previous year was comparable during the winter months, there may have been more solar radiant energy in April and colder temperatures.

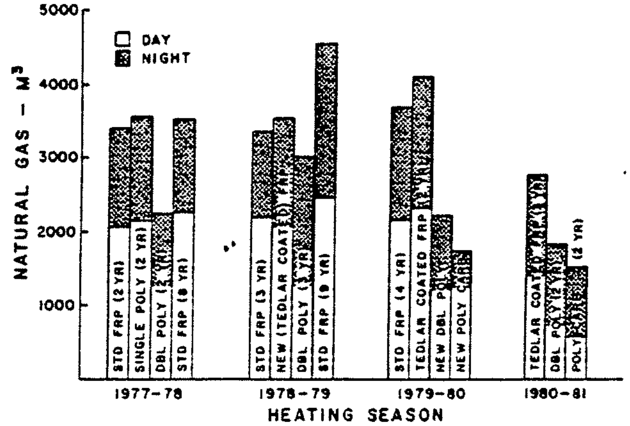

Fig. 2. Comparison of natural gas required to heat identically designed quonset greenhouses, with different covers, during daylight and night hours for 150 days (Dec. 17 through May 17) from 1977-81.

Night fuel consumption. The most important aspects of greenhouse fuel consumption is the relationship of night fuel requirements to those during the day. Tristan (1977) confirmed data of several other researchers when he determined approximately 70 percent of the total fuel required to heat a greenhouse is used at night. The mean minimum temperatures of Table 1 can be directly associated with the fuel requirements shown in Figure 2. During the 1978-79 season the old FRP cover became very brittle, thin and cracked in places, which had to be patched. It was apparent that many of the cracks did not freeze shut during cold weather, which contributed to greater fuel consumption in 1978-79. The fuel required by the single poly house was almost identical to that used by the FRP covered house in the 1976-78 seasons. The condensate formed on the inside of the poly apparently created an insulation affect.

The percent of fuel required at night by the greenhouses, Table 4, did not vary appreciably and was well in the ranges previously reported.

Table 3. Fuel consumption in four identical greenhouse structures with different covers through a 150 day period (Dec. 17 through May 17), 1976-1981.

House	1	2	3	4
1976-77	STD FRP (NEW) 5079[z]	SGL POLY (NEW) 6% >[y]	DBL POLY (NEW) 33% <	OLD FRP (8 YRS) 11% >
1977-78	FRP (2 YR) 5420[z]	SGL POLY (2 YR) 5% >[y]	DBL POLY (2 YR) 36% <	OLD FRP (9 YRS) 6% >
1978-79	FRP (3 YR) 1% <	NEW FRP 5595[z]	DBL POLY (3 YR) 24% <	OLD FRP (10 YRS) 25% >
1979-80	FRP (4 YR) 8½% <	FRP (2 YR) 6356[z]	DBL POLY (NEW) 46½% <	POLY CARB (NEW) 54% <
1980-81		FRP (3 YR) 4148[z]	DBL POLY (2 YR) 41% <	POLY CARB (2 YR) 51% <

[z] M³ of natural gas used by "base" house.
[y] Signs designating (>) greater than or (<) less than base.

Table 4. Percent of total fuel consumed at night in quonset greenhouses covered with different covers.

Cover	Years of Data	Range of Percent
STD. FRP 5 OZ	4	60-63 (62)
TEDLAR/FRP 5 OZ	3	63-66 (64)
DBL POLY, 6 MIL AIR-INFLATED	4	64-72 (68)
DBL WALL POLY-CARBONATE	2	58-73 (66)

( ) = Average for the years.

Discussion

Many greenhouse researchers have used the number of "degree days" as an indicator of fuel required by one greenhouse vs. another or from year to year. The "degree day" is determined by averaging the maximum and minimum daily temperatures and subtracting it from 65°. The fuel consumption is then correlated with the degree day temperatures.

Such a procedure is more meaningful for computing home fuel consumption because solar energy has little affect, however, other factors are not considered. The "degree day" doesn't include the time a temperature remained at any level, the wind factors are not incorporated and for greenhouses purposes, insolation effects on fuel consumption are completely overlooked.

Some greenhouse researchers have considered computer "modeling" as a prediction or to determine the influences of the atmospheric conditions on fuel consumption. Once again such a procedure is unrealistic. First, an accurate accounting of water vapor in the air, outside temperature levels and duration, solar radiant energy and greenhouse cover transmission characteristics must be included. Wind, another factor, is impossible to measure according to meteorologists, and translate into usable data. It gusts, changes direction, stops and etc. all in relation to time.

How is wind to be identified — realistically it is impossible. Growers, researchers, and greenhouse fuel conserving equipment representatives must realize that a particular conservation system will not provide the same savings each day, week, month or year. The geographical location has a definite influence that may outweigh all of the other factors.

Some of the data presented in this article may also be misleading. Some researchers (Ross et al. 1978) have suggested lowering greenhouse temperatures a few degrees to conserve fuel and the advise is reasonable. It is possible that temperatures in one house were one or two degrees different than another, for periods of time. Or, one house was influenced by some exterior condition (snow, wind) more than another. Such potential problems can be reduced if proper experimental design is incorporated. In this case, replication of facilities were impossible and the next best approach was to have several years of data and observations.

Double layer covers are probably the most valuable and expediant method of lowering fuel costs, especially for new greenhouse construction within specific geographical locations. Research must continue to determine which double covers are the most economical in relation to longevity, efficiency and crop responses.

References

Goldsberry, K.L. and John Tristan. 1977. Greenhouse Heat Conservation. Part I. Colo. Flr. Grow. Bull. 330.

Hanan, J.J., W.D. Holley and K.L. Goldsberry. 1978. Greenhouse Management. Springer-Verlag, N.Y.

Hay, James W. and K.L. Goldsberry. 1978. Greenhouse Heat Conservation. Part II. Colo. Flr. Grow. Bull. 333.

Ross, D.S., W.J. Roberts, R.A. Parsons, J.W. Bortok Jr. and R.A. Aldrich. 1978. Energy Conservation and Solar Heating for Greenhouses. NRAES-3. Agricultural Engineers, Univ. of Maryland, College Park, MD.

Sherry, William and K.L. Goldsberry. 1978. Night Heat Requirements of Plastic Covered Greenhouses. Colo. Flr. Grow. Bull. 334.

White, J.W. and R.A. Aldrich. 1976. Energy Conservation Systems for Greenhouses. Bull. 286. Penn. Flr. Grow. Bull. 1976.

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