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PLANT GROWTH RESPONSE TO THE TRANSMISSIVITY OF

GLASS REINFORCED THERMOSETTING PLASTIC PANELS

by

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Approved:

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In Charge of Major Work

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Dean of Graduate College

Iowa State University
Of Science and Technology
Ames, Iowa

1969

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INTRODUCTION

Since the discovery that green plants assimilate carbon in the presence of light, physiologists and ecologists have recognized light as one of the most important factors in plant growth. To date, most research involving the effects of light on plants has been conducted in standard glass structures and detailed radiation studies have been accomplished with light from artificial sources.

The use of controlled environments specifically designed to examine various plant growth responses (17, 34, 72) has led to renewed investigations involving light and plant growth. The advent of fiberglass reinforced plastic (FRP) panels for greenhouse coverings, has made it necessary to use the light transmission potential of this material as a foundation for controlling plant environment using insolation as the main source of light energy.

Plant growth is improved when all wave lengths of the visible spectrum are available and in some cases it has been shown that only energy directly from sunlight provides the best plant growth (49, 52). Under laboratory conditions photosynthetic activity is greatest when specific wave lengths of red and blue are available (12, 14).

Little work has been done to determine why plants respond so well to full sunlight. This investigation was designed to evaluate plant response to insolation in terms of wave length intensity ratios and radiant energy transmission by flat glass and corrugated fiberglass reinforced thermosetting plastic panels.

OBJECTIVE

The objective of this investigation is to determine the growth response of plants to heat and light quality and quantity transmitted through colored and noncolored fiberglass reinforced thermosetting polyester resin panels.

The investigation was divided into two parts:

Part I A preliminary study to determine some of the plant environmental characteristics created by coverings of FRP frost white, clear and super clear panels, and glass.

Part II The evaluation of plant growth under the lowest possible amount of insolation transmitted by tinted panels of FRP with transmission characteristics in the violet, blue, pink and red regions of the visible spectrum.

REVIEW OF LITERATURE

Coverings for Plant Growth

Historians do not document the exact inception of growing plants under cover, but Lemmon (38) recorded the writings of Plato, who in the fourth century B.C. indicated in his Phaedon that plants were grown under protection. Lemmon also noted that Sir Joseph Banks mentioned the forcing of dessert fruit in Roman times under thin sheets of mica called "muscovy glass" (lapis specularis). One of the first references of glass use was in 1385 in the Bois de Duc in France, where they grew flowers in glass pavilions facing south (38).

Glass

Flat glass During the past six centuries, glass has been the main transparent medium used to provide natural light in protected environments for plant growth. Through the early seventeenth century arguments and theories about covered garden buildings were common. The first greenhouse building material to come under the closest scrutiny was glass. For several hundred years, only two types of glass had been used. One was Broad glass which was made by dipping a metal cylinder in molten glass, then stripping off the glass and ironing it out. Broad glass tended to be uneven in thickness, and was usually streaked. The second type, Crown glass, was made by spinning a circle at the end of a glass blower's pipe. It had a greenish cast and was favored by gardeners (38).

By 1883, sheet glass was being produced. It was said of the garden house . . . "one of the greatest improvements made in their construction since the substitution of roofs of glass for those of opaque material (38)." Most glass used at the turn of the nineteenth century was of good quality sheets weighing from 21 to 24 ounces per square foot. Some translucent corrugated sheet glass and unpolished plate-glass had been tried for plant covers, but was generally found unsuitable because of insufficient light during dull weather (46).

Glass used in the construction of plant covers today is still largely soda-lime-silica glass. For many years the Federal Government has maintained specifications for all types of glass. The following requirements for greenhouse glass are taken from the latest specifications (70).

designation: Double strength, having a minimum and maximum thickness of 0.115 and 0.134 inches respectively.

cut size: The length and width cut size tolerance is 1/32 inches.

quality: Glass may contain defects of any size or intensity, but shall contain no stones which may cause spontaneous breakage.

sheet: Greenhouse quality, intended for use in greenhouse glazing or similar applications where quality is unimportant.

The definition of sheet glass in the Federal specification is: "Transparent, flat glass having glossy, fire-finished, apparently plane and smooth surfaces, but having a characteristic waviness of surface."

Fiberglass "Fibrous glass," more recently known as fiberglass was used in a coarse form by Egyptians before the time of Christ. The Columbian Exposition of 1893 featured glass fiber clothing and the Germans, during World War I, were unable to obtain asbestos and turned to fibrous glass as a substitute (51).

It was not until 1931 that fiberglass was first marketed in the United States and consisted of such items as insulation, reinforcing mats, and thread (50). Mats of fiberglass, made from low alkali lime soda borosilicate, were generally used for plastic-mat lamination. When molten glass is passed through spinnerets with high pressure steam, fibers form and are deposited on a conveyor belt in a web-like mat. The mat is then coated with a binder, oven dried, and ready for lamination (26).

Plastics

There are many plastic resins used in the industry today. Most of these resins have been classified into two categories, thermosetting and thermoplastic. Thermosetting resins are those materials that undergo a chemical polymerization reaction or "cure" upon initial heating. Reheating does not reverse the process or change the physical condition. Thermoplastic materials when reheated merely change physical condition and become soft and hard when cooled (66).

The earliest known thermosetting plastic -- a phenol formaldehyde resin called "Bakelite" was developed in 1909. The first thermoplastic, cellulose nitrate, given the trade name "celluloid" was discovered in 1868. Because of the highly flammable characteristics of cellulose nitrate it was not marketed and in the 1930's cellulose acetate was introduced (11).

Film materials   The first flexible film, a thermoplastic material was developed by British chemists, Faucett and Gibson in 1933. The first ton of the film, called polyethylene, was produced in England in 1938. However, production did not start in the United States until 1943 (11). The earliest known use of polyethylene film for plant protection and growth in the United States was suggested by Emmert (15) in 1954. Other films often used for plant coverings include polyvinyl, Mylar[1] (a polyester), Kodapak (a cellulose), and polystyrene (69). Japan uses a large amount of polyvinyl chloride film for plant covers. The film was introduced in approximately 1951 and now comprises almost 70% of all coverings used in Japan (53).

Rigid materials   During the past decade rigid plastic coverings for plant production have been well received because they provided adequate light transmission, decreased building

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[1]Trade names

costs and facilitated rapid construction. In general, the following three plastic products compose the major materials.

Plexiglas The most transparent rigid plastic produced is an acrylic monomer called Plexiglas. Acrylic monomers were reported as early as 1843, but it was not until 1901 that Dr. Rohm of Germany reported on acrylic materials and in 1927 directed the first commercial manufacture of the resin (3, 20, 41, 48).

Polyvinyl Chloride (PVC) Rigid PVC panel production began in the United States around 1959. However a light-stable product for greenhouse glazing could not be produced. The Japanese produced a panel for export in the late 1950's, but it proved to be light sensitive and turned "yellow" within 18-24 months. At this time, the only apparently light-stable PVC being utilized in the United States for plant protection is that produced by the Hishi Nami Company of Japan.

Fiberglass Reinforced Plastic Panels (FRP) The first known FRP panels in the United States were produced in approximately 1947. These translucent thermosetting panels were mainly used as skylites in corrugated metal buildings. The panels were basically composed of polyester resin, catalyst, filler, and glass mat (64). After approximately two years exposure to nature's elements, the panel started eroding, exposing the glass fibers.

By the mid 1960's the FRP panel had been improved with the addition of an acrylic monomer. Figure 1 shows a generalized flow diagram of materials for the present day production of glass reinforced plastic panels (3, 18, 47). New formulations have improved the FRP panel providing increased weatherability, transmission stability and longevity.

One of the earliest evaluations of FRP as a cover for plant growth was by Holley (31) in 1956. In 1958 Carpenter (9) built a greenhouse structure of wood and FRP for plant growth evaluations. In the summer of 1959, Briggs (6) compared the growth of carnations under glass, several plastic films and FRP. From 1958 to 1960, White (73) evaluated the growth response of several plant species grown under clear FRP. Work at Colorado State University in 1966 (32) indicated that the frost type fiberglass yielded greater growth than clear FRP, PVC panels or glass. All research to date indicates that plants grown under translucent FRP panels are equal to or superior to those grown under glass.

Inferences are often made regarding the superior growth of plants achieved under polyethylene compared to other plastics. Two recent investigations (10, 60) indicated no significant differences in the yield or quality of tomatoes grown under four types of plastic, including FRP.

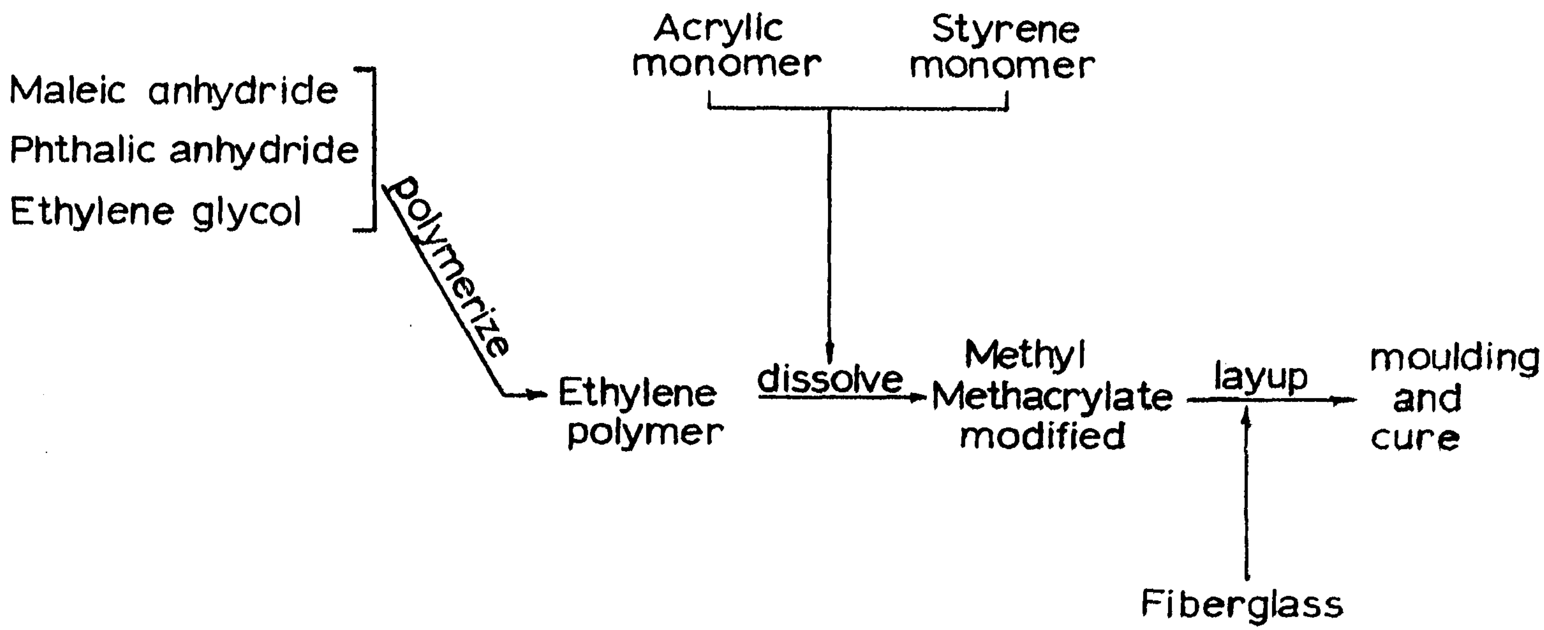

Figure 1. Flow diagram showing development of fiberglass reinforced plastic panels.

Cover Transmission Qualities

An early account of heat transmission through a glass and its effect on plant growth was demonstrated when the Kew Garden palm house was constructed in approximately 1833 (38, 39). The intense light passing through the glass was assumed to cause a "burning" on the palm leaves and a pale yellowish green tinted glass was recommended and was manufactured to decrease heat transmission. The theory may have been correct, but the tinted glass was later replaced with colorless glass.

Brigg's studies (6) demonstrated significant differences in the heat transmission of a clear FRP and glass. Using an Epply pyrheliometer as a means of comparison, clear FRP transmitted 12 percent less solar energy than glass. Others (28, 73) also found that light was reduced on sunny days under FRP when compared to glass. Later research by Aldrich _et_ _al_. (1) indicated that a glass house transmitted approximately 24 percent less energy than a house covered with FRP. The study by Briggs was conducted in an identical time of year and appears to be in direct conflict to that of Aldrich.

Goldsberry (23) showed that the spectral transmission characteristics of new glass, standard glass 12 and 43 years old and one quarter inch glass 43 years old were not significantly different within the visible portion of the spectrum. Researchers in England (69) concluded that radiation transmission and heat conserving properties of ten plastic films were not superior to glass.

Studies conducted in Ames, Iowa (24) showed that spectral transmission characteristics of FRP were controlled by the degree of translucence and color of the materials. The greatest transmission differences, in relation to the total insolation, occurred in the lower end of the visible spectrum. All clear plastic materials had comparable transmission curves and were aligned almost midway between curves of new glass and coral FRP in the visible portion of the spectrum.

Plant Responses to Light Quality

Researchers have demonstrated the importance of the light spectrum reaching a particular plant environment and have often indicated that continued study and application were long overdue (2, 24, 36).

The research of Mr. R. Hunt, involving light quality and its effect on plant growth and his presentation of data to the British Research Association in approximately 1844 is described by Lemmon (38). The data presented in his paper showed that the "natural conditions" of plants could be altered by red, blue and yellow light. Yellow light prevented seed germination and in most cases young plants died. Light transmitted through a red medium was not unfavorable to seed germination but plants were elongated. Blue light accelerated the germination of seed and caused rapid, weak growth of young plants and when they were given yellow-green light, plant growth improved.

During the same year, Dr. Horner of Hull, England experimented with glass for greenhouse purposes and recommended violet-colored glass (38). The following sentence provides an insight to his thinking.

> "As not only affording partial shade but as transmitting a light which possesses a subtle action in exciting vegetation and proving in all respects an admirable auxilary to heat and moisture necessarily employed in culture."

His recommendations were not heeded.

Light transmitted through colored coverings

Aside from the unsuccessful use of green tinted glass on the Palm house in Kew Gardens (38, 39), many researchers have studied the effects of colored coverings on plant growth. Schanz (61) covered eight beds with various colored glass, transmitting decreased quantities of blue-violet light. Maximum plant height of soybeans, potatoes, red beets, and beans was obtained under red light and minimum height under blue-violet. In general Schanz concluded that short wave lengths, particularly UV, are detrimental to plant growth. For greenhouses he recommended Euphos glass which prevents the transmission of UV rays.

Popp (52) compared the growth of plants receiving unobscured solar radiation to those grown under glass coverings transmitting various amounts of violet and blue light. He noted little difference in plants grown without UV and those grown in full sunlight, but when wave lengths shorter than 529 mμ were removed, poor growth occurred, stems were weak and fresh and dry weights were lower.

Anatomical studies of plants grown under Corning glasses transmitting five types of light (49) yielded results comparable to those of Popp. Cross sections of Biloxi soybean were similar for full spectrum and outdoor grown plants. In general, the stem diameters of all plant species studied were smallest under red and blue light. Stem height was least under blue and greatest under red light. Leaves were thinnest under red with blue light next. Pfeiffer (49) indicated that the full solar spectrum provided better development than any modified spectrum as demonstrated by more differentiation, greater height, increased stem and leaf thickness and root systems of plants studied.

One of the earlier reviews concerning the effects of light on the physiological processes of plants was by Burkholder (7). Because of his excellent review, additional evaluations of work prior to 1936 will not be presented here.

Briggs (6), compared carnations grown under seven colors of FRP corrugated panels to those grown under glass and noted that significantly more dry matter was produced under the clear, coral, amber, jade and frost colors than under glass.

The lavender and yellow FRP coverings yielded less dry weight than did glass. Growth of carnation plants under clear fiberglass was also superior to growth obtained under glass or coral FRP. The percentage of blue light transmitted by the coral FRP was less than half of the red light transmitted (24).

Effects of artificial light

Evaluations of colored artificial light on plant growth appears to substantiate the experimental results with natural light and colored coverings.

Dunn and Went (14) compared dry weights of tomato plants grown under combinations of blue, green, gold, pink and red fluorescent lights. Plants grown under blue and red light provided the most dry weight and the green and yellow light reduced photosynthesis. Other experiments involved combinations of blue, red, warm white and green light. The combination red and blue light provided the greatest plant growth and the photosynthetic efficiency was as high as the efficiency under separate blue or red lights. Dunn and Bernier (13) indicated that the Gro-Lux fluorescent lamps provide "proper" balance of the light spectrum and are comparable to solar radiation.

Van der Veen and Meijer (71) showed that the effects of red and blue light intensity on stem elongation could be reversed. At low light intensities blue light is always less active than red, at higher intensities the reverse is true.

Photosynthesis

Since 1882 when Engelmann (16) found that two peaks of effectiveness in the light spectrum, 400 and 600 mμ were responsible for photosynthetic activation, many researchers have verified his data. A reference frequently cited is Hoover (33) who determined the photosynthetic spectral requirements for young wheat plants. He found that maximum CO_2 absorption occurred at peaks of 440 and 655 mμ. He also noted increased reflection and transmission of radiation in the green region by plant leaves diminishes the effectiveness of photosynthetic activity. Loomis (43) and others (54, 63) have shown absorption spectra of the intact leaf to be different from that of chlorophyll in ether or water. Loomis found that the absorption spectrum of approximately 90 plant species peaked between 450 and 500 mμ and again near 700 mμ. M. Hommersand and F. Haxo (Ray (57)) observed two peaks in the photosynthetic action spectrum of *Elodea densa* leaves. The highest peak was at approximately 435 and the lower peak at 670 mμ. Machlis and Torrey (44) studying photosynthetic processes also found two peaks of activity, one in the blue range between 400 and 450 mμ, the other in the red range around 650 to 670 mμ.

The photosynthetic activity of several algae are also effected by light quality. Levring (40) studied the effects of ocean depth on algae activity. He showed that the photosynthetic activity of *Enteromorpha clathrata* decreased with depth. At the 0.5 meter depth, an action range in blue (near 440 mμ) and red (645-660 mμ) were predominate. Increases in depth decreased both peak areas and at 20 meters, no action peaks were visible graphically.

Terborgh *et al.* (68) studied the low effects of light on growth and pigment content of *Chlamydomonas reinhardi* and showed peaks of effectiveness between 462 and 502 mμ, a region in which carotenoids absorb strongly, and between 700 and 736 mμ where long wave length forms of chlorophyll a are known to absorb.

Krey and Govindjee (37) report that a major band at 693 mμ appears when the fluorescence of porphyridium is excited by high intensities of green light when compared to the same cells given low intensity green light. Minor positive (669 mμ) and negative (660 mμ) bands also appear. It is suggested that a shift of fluorescence of phycocyanin caused the changes.

Pigment formation and absorption

The wave lengths of the light spectrum most active in photosynthesis are essentially the most effective in chlorophyll formation. Sayre (59) found that no chlorophyll developed in plants that were radiated only with wave lengths longer than 680 mμ. Frank (19) found that blue and red light are highly effective for chlorophyll absorption but blue at 440 mμ is dominant. Livingston (42) noted absorption peaks of 435 and 667 mμ in chlorophyll and in chlorophyll b, 472 and 660 mμ. Jagendorf (35) presented a table relating the peak absorption wave lengths for various photosynthetic pigments in green plants. Chlorophyll a, b, and c ranged from 640 to 673 mμ, Beta-carotene, 482 mμ, fucoxanthin, 470 mμ and phycoerythrin, 566 mμ. French (21) presented a complete absorption spectrum of chlorophylls a and b in ether. Chlorophyll a peaked at 430 and 637 mμ and b at 455 and 662 mμ. The "second Emerson effect"[1] no doubt plays a part in the overall absorption spectrum of pigments. It varied with the plant according to Govindjee and Rabinowitch (25) and peaks ranged from 570 to 700 mμ. Violaxanthin from pansies, brown algae and green leaves showed two spectral absorption peaks in the blue range, 472 and 442 mμ. Mohr (45) presented an action spectrum for anthocyanin formation in <u>Sinapis</u>. Peaks were at 475 and 725 mμ. Several other researchers studying the absorption spectrum of plant pigments have found similar results (55, 57, 61).

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[1]The second Emerson effect is the increased photosynthetic activity of far red light caused by a simultaneous application of light with shorter wave lengths.

Other photophytological processes

Phototropism   Comprehensive quantitative observations on light intensity and wave length relations in phototropic responses were made by Blaauw (5). His work showed that blue light is phototropically the most effective and has since been verified by many investigators including Seliger and McElroy (62). An action spectrum for the positive curvature of *Avena* coleoptiles was developed by Seliger and he noted a main energy peak at 445 mμ with secondary peaks around 430 and 470 mμ.

Photoperiodism   Hendricks and Borthwick (29) have extensively investigated the action of red (around 660 mμ) and far red (approximately 730 mμ) light on the growth of Pinto beans. They were able to promote or inhibit leaf expansion by alternating doses of red and far red light and the last exposure created the dominating effect. They termed the receptor pigment involved in the phenomenon, phytochrome. Salisbury (58) has shown that the flowering of short-day plants is inhibited and flowering in long-day plants promoted by a red light interruption of the dark period. The response is reversed by far-red light, if it is given immediately following the red. The controlling factor in photoperiodism appears to be the phytochrome system (58).

Additional photophytological processes including the photochemical apparatus related to photosynthesis, photoaxis and the high-energy reaction system of photomorphogenesis are beyond the scope of this review.

It is apparent that many of the photo-stimulated responses related to plant growth occur within the blue and red regions of the light spectrum. The light quality and quantity utilized by plants for "normal" growth in greenhouses can conceivably be modified. Thus the transmission characteristics of FRP panels in the blue and red portion of the spectrum could relate directly to plant growth, providing all other growth factors are in equipoise.

PART I

GROWTH RESPONSES OF DIANTHUS CARYOPHYLLUS TO SPECTRAL AND HEAT TRANSMISSION BY GLASS AND GREENHOUSE GRADE FIBERGLASS REINFORCED PLASTIC PANELS

MATERIALS AND METHODS

Facilities

A greenhouse 72' x 15', oriented east and west and consisting of four compartments (A, B, C, and D) was used for this investigation (Figure 2). Each compartment was 18' x 15' and covered from west to east with greenhouse grade panels of FRP[1] frost white, clear and super clear[2] respectively. The covering[3] on the fourth compartment was twelve year old greenhouse glass. The frost covering, installed in June, 1964, was unusually darkened by age when compared to new material. The clear panels were installed in the fall of 1965 and the super clear material, June 1967. Cooling and heating equipment is described by Hanan (27).

A redwood bench 40 inches wide x 144 inches x 8 inches deep was centered in the north and south halves of each compartment. Only a portion of the north bench was used in this investigation.

Each compartment was heated to 60°F and cooled to 65°F during daylight hours. Night temperatures were controlled at 53°F ± 1.°.

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[1]FRP = Fiberglass Reinforced Plastic

[2]Super clear is a term applied to exceptionally clear FRP panels used as greenhouse covers.

[3]The terms covering, treatment and panels are used interchangeably throughout the dissertation.

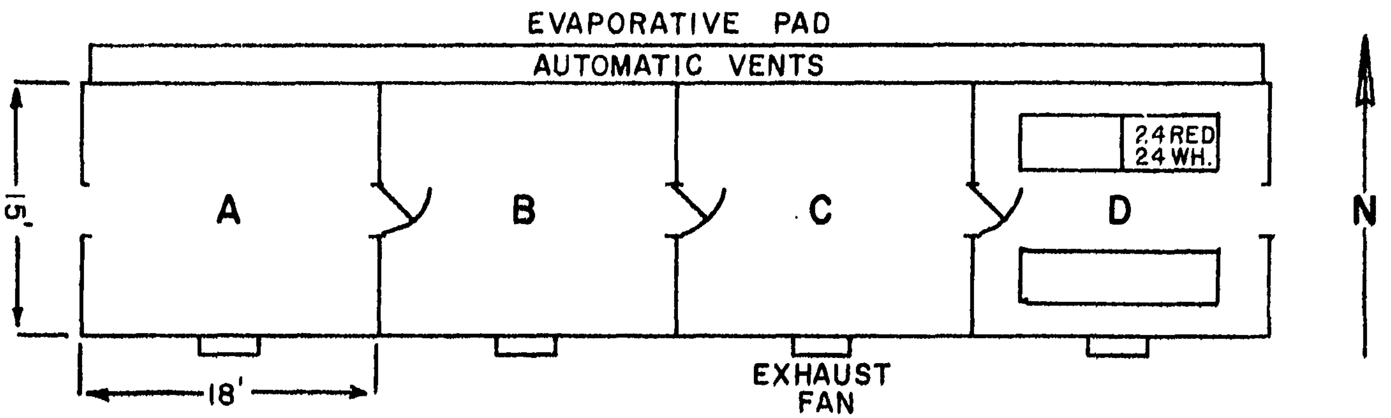

Figure 2. Floor plan of Colorado State University temperature greenhouse with environmental controlled compartments covered with glass (D) and FRP panels of frost (A), clear (B) and super clear (C).

Humidity was not controlled. Generally, free water was present on the compartment floors and the relative humidity seldom went below 30%.

Atmospheric carbon dioxide concentrations were periodically monitored in each compartment with a Beckman model LB 15A infrared gas analyzer and injection rates were adjusted to maintain at least 500 ppm during daylight hours and periods of non-ventilation.

The north bench of each compartment contained a commercial medium called Idealite, a hard pervious substance capable of retaining adequate moisture and providing excellent water drainage and aeration. The medium was steam sterilized before planting.

A peripheral watering system irrigated the plants automatically three minutes twice each day until November 1, three minutes once each day November 1 to March 1 and then twice a day. Irrigation was controlled in all compartments by a common electric timer-solenoid combination.

A Smith model R-B fertilizer injector was used to inject nutrients into the irrigation system each time the plants were watered at a rate of: N, 178; k, 154; Mg, 12; P, 15; and B, 10 ppm per 1000 gallons of water.

Plant Materials

Twenty four rooted carnation cuttings (Dianthus caryophyllus) of the varieties CSU Red and White Pikes Peak, were planted at random, three per sq. ft. in a 48" x 42" plot in each compartment on July 18, 1967 (Figure 2). The cuttings were obtained from foundation stock at Colorado State University. The terminal growing tips of all plants were removed approximately four weeks after planting and the plants grown for flower production using standard growing procedures.

Measurements

All measurements were taken in Fort Collins, Colorado (105^{o} -04' west longitude and 40^{o} -35' north latitude) at an elevation of 5,080 feet above sea level and between September 30, 1967 and June 21, 1968 to evaluate the growth response to spectral and heat transmission of the four coverings.

Yield

The flower production between November 26, 1967 and June 23, 1968 was recorded. Additional measurements included fresh weight, length from the top of the calyx to the cut end of the stem, and length of the second and fourth internodes below the calyx.

The reproductive buds occurring along the flower stem and the first vegetative break below the calyx were harvested biweekly starting November 11, 1967, for fresh and dry weight measurements.

Temperatures

All surface temperature measurements were obtained with a Barnes infrared thermometer.[1] Measurements were from black and white construction paper, red and white flower heads and plant foliage. The black and white surface temperatures taken in each compartment and outside were on a plane perpendicular to the sun. Readings were not corrected for the emissivity of the surfaces.

Inside and outside air temperatures were monitored with a 24 point thermocouple recorder.

Spectral transmission

The spectral distribution of outside solar radiation and that transmitted through the covering on each compartment was measured with an ISCO model SR and SRR recording Spectroradiometer. The instrument, periodically calibrated, measured the electromagnetic spectrum between 400 and 1550 millimicrons. Measurements inside were made with the sensing element placed at flower head height and parallel to the horizon.

Heat transmission

Heat transmission data were obtained with Sol-A-Meter Mark II pyranometers which responded from 350 to 1150 millimicrons, peaking at 850 millimicrons.

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[1] Sensitivity of instrument, 8 to 14 microns.

All radiation and temperature measurements were taken on approximately 14 day intervals between December 21, 1967 and June 22, 1968 and when the sun was at maximum daily altitude and/or between 11:00 a.m. and 1:00 p.m. Mountain Standard Time.

Statistical Analysis

A complete statistical analysis was performed using the CED G400 computer and the "canned" programs available from the Biometrics Unit of the C. S. U. Statistical Laboratory. Variance was determined for the various responses of interest. Statistically significant factors were further investigated using methods of multiple comparisons, graphical techniques, and other suitable statistical methods. Tukey's w-procedure called the honestly significant difference (HSD), which is similar to the LSD test, was used to evaluate the significance of most data (67).

RESULTS

Plant Characteristics

Yield and stem length

Between November 26, 1967, and June 23, 1968 the greatest number of both red and white flowers were produced under the super clear FRP covering and the least under the frost cover (Table 1). Production under super clear was 20.3 and 12.0 respectively. Total production under clear and super clear was not significantly different.

Stem length The stem lengths[1] of the red flowers grown under glass were shortest and were progressively longer under the clear, super clear and frost respectively. There was no significant difference between lengths of red flower stems grown under the frost and those grown under the super clear coverings (Figure 3). The length of both red and white flower stems produced under all FRP covers was significantly longer than those grown under glass (Table 1). The stems of the white carnations grown under frost were significantly longer than those from all other covers.

Internode lengths Total stem length, a function of internode length, can be controlled by one, several or all

[1]All flowers were cut directly above the seventh node below the calyx.

Table 1. Production characteristics of white Pikes Peak and CSU red carnation varieties grown under coverings of glass and FRP panels of frost, clear and super clear between November 26, 1967 and June 23, 1968.

COVER	TOTAL FLOWERS		MEAN WEIGHT (gms)		MEAN LENGTH (cm)		SECOND INTERNODE (cm)		FOURTH INTERNODE (cm)	
	RED	WHITE	RED	WHITE	RED	WHITE	RED	WHITE	RED	WHITE
FROST	227	268	27.67	27.60	51.14	51.66	3.57	3.83	10.62	11.51
CLEAR	233	316	26.25	27.26	47.69	50.19	3.74	3.73	10.53	11.44
S. CLEAR	288	333	29.66	27.58	50.21	50.03	3.22	3.77	11.08	11.32
GLASS	267	279	27.87	26.76	46.51	48.20	3.13	3.37	10.29	10.85
Q=HSD[a]			1.04	1.04	1.08	1.08	0.30	0.30	0.23	0.23

[a]Tukey's honestly significant difference

internodes. No significant differences occurred in the mean lengths of the second and fourth internodes of white flowers grown under FRP covers (Table 1). Both the second and fourth internodes of all flowers grown under glass were significantly shorter than under any FRP treatment except the second internode of red flowers produced under the super clear cover.

Growth

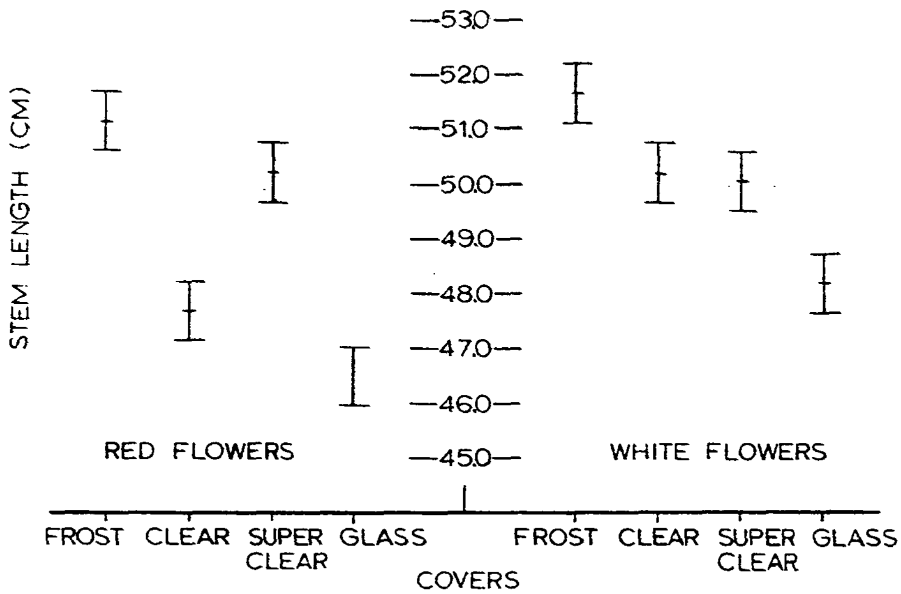
Both fresh and dry weights of flowers, vegetative breaks and lateral buds produced under each cover were evaluated.

Flower weights The fresh weight of red flowers grown under the super clear cover was significantly greater than under all other covers. No significant differences in weight occurred between those grown under the FRP frost and glass covers (Figure 4). The lightest weight red flowers were grown under the clear covering. There were no significant differences in the weights of white flowers under all covers (Figure 4).

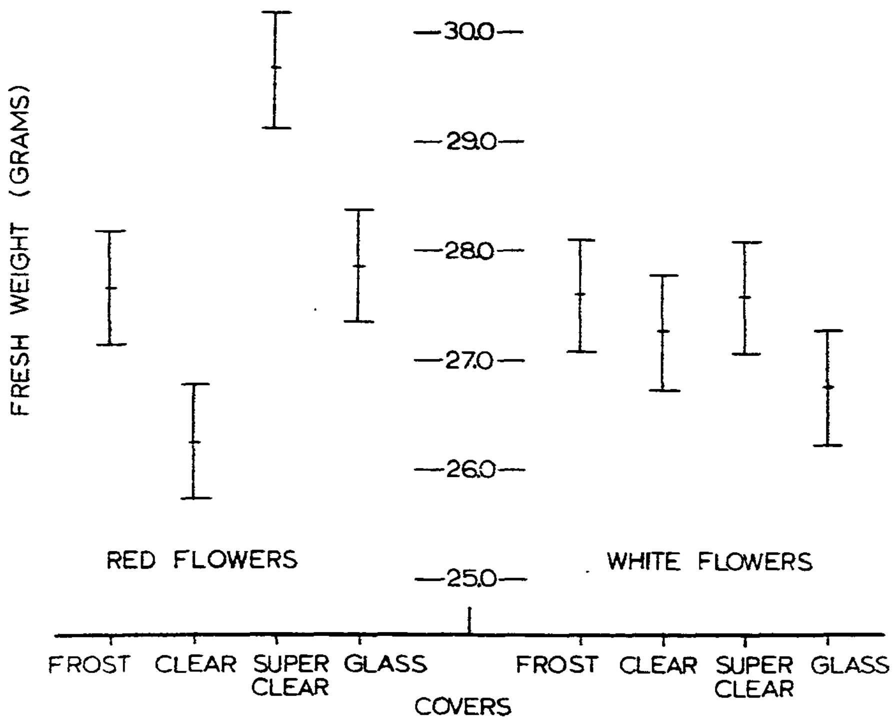
Vegetative breaks There were no significant differences in the biweekly production of the first vegetative breaks below all flower calyxes (Table 2). The dry weight of breaks produced under the super clear cover was only significantly greater than dry weight production of breaks under the frost treatment. The mean fresh weight of each break produced under all covers was not significantly different.

Figure 3. Stem length confidence intervals (95 percent) of red and white carnation flowers produced under coverings of glass and FRP panels of frost, clear and super clear.

Figure 4. Fresh weight confidence intervals (95 percent) of red and white carnation flowers produced under coverings of glass and FRP panels of frost, clear and super clear.



STEM LENGTH (CM)
53.0
52.0
51.0
50.0
49.0
48.0
47.0
46.0
45.0
RED FLOWERS
WHITE FLOWERS
FROST
CLEAR
SUPER CLEAR
GLASS
FROST
CLEAR
SUPER CLEAR
GLASS
COVERS



FRESH WEIGHT (GRAMS)
30.0
29.0
28.0
27.0
26.0
25.0
RED FLOWERS
WHITE FLOWERS
FROST
CLEAR
SUPER CLEAR
GLASS
FROST
CLEAR
SUPER CLEAR
GLASS
COVERS

Table 2. Mean fresh and dry weights and percentage dry matter of disbuds and first vegetative breaks produced by white Pikes Peak and CSU red carnation varieties grown under four coverings between November 11, 1967 and June 25, 1968.

	BREAKS				BUDS		
COVER	NO BREAKS BIWEEKLY	MEAN FSH[b] WT/ BRK	MEAN DRY[b] WT/ BRK	PERCENT DRY MATTER	BIWEEKLY[b] MEAN FSH WT	MEAN[b] DRY WT	PERCENT DRY MATTER
FROST	18.84	2.07	0.297	14.34	84.72	14.30	16.88
CLEAR	20.84	2.25	0.344	15.29	105.84	18.16	17.15
S. CLEAR	23.05	2.36	0.357	15.13	127.68	22.60	17.60
GLASS	20.47	2.19	0.325	14.84	116.44	21.69	18.63
Q = HSD[a]	4.59	0.47	0.047		29.42	5.35	

[a]Tukey's honestly significant difference

[b]All weights in grams

Lateral buds   The fresh and dry weights of lateral buds produced under the super clear cover differed significantly only from those produced under the frost cover (Table 2).

Transmission Characteristics

Spectral transmission

The mean spectral transmission curves (400 to 750 mμ) created by the four treatment covers on twelve random unobscured (cloudless) days between December 21, 1967 and June 22, 1968, are shown in Figure 5. The percentage of unobscured insolation received under the same four coverings are shown in Figure 6.

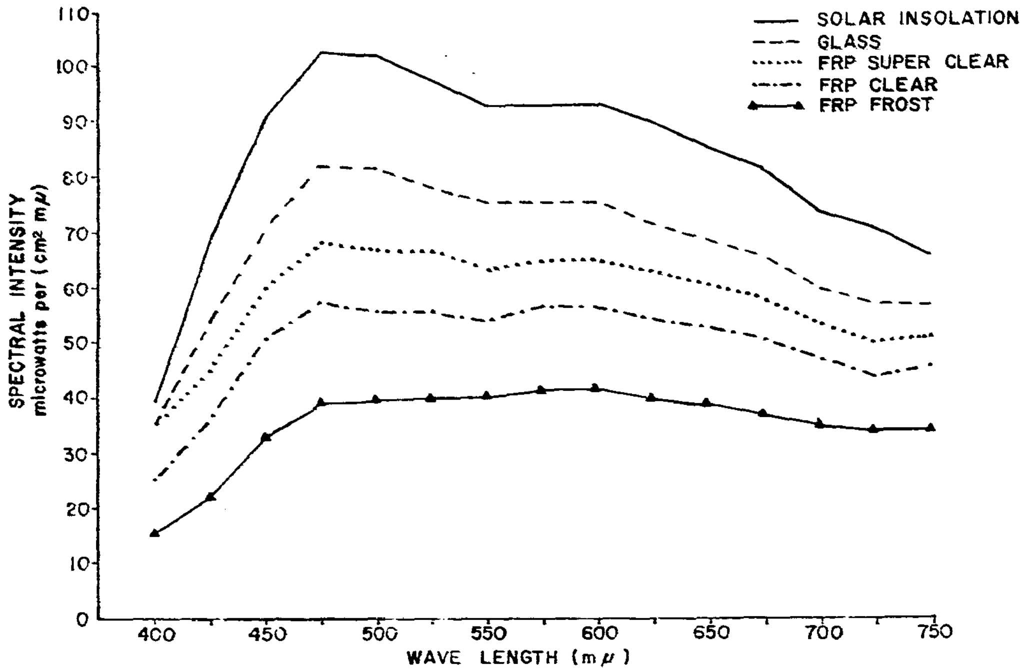
Spectral transmission characteristics (400-1500 mμ) of the four covers are contained in Appendix A.

The differences in transmission characteristics of the four coverings were compared to insolation on May 13, 1968, an unobscured day, and May 15, a day of total overcast. During periods of total overcast there were no significant differences between the spectrums transmitted by the four coverings (Figure 7).

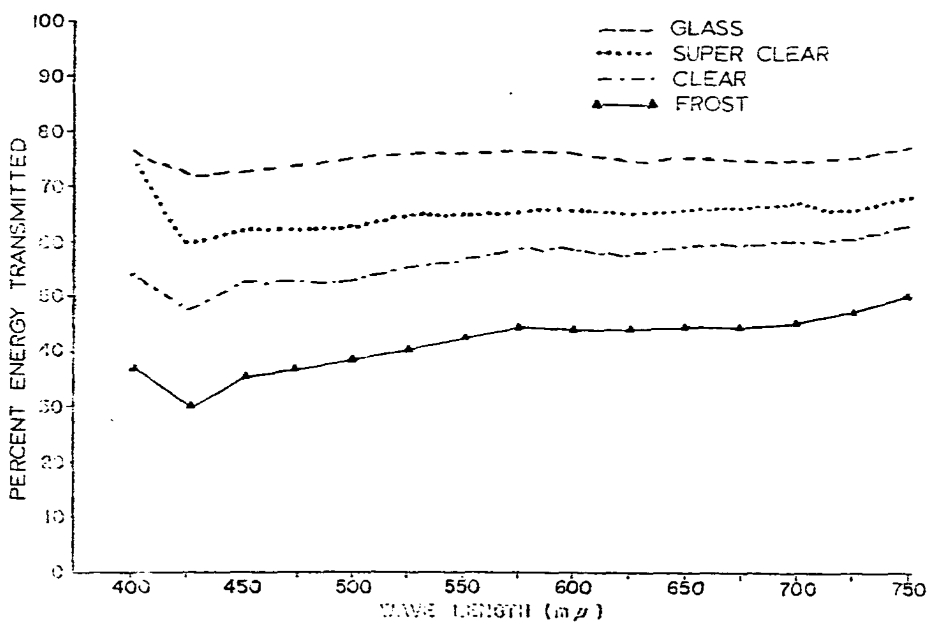
Color bands   The visible light transmitted by each cover was divided into four color response bands: blue, 425-475 mμ; green, 525-550 mμ; red, 625-675 mμ and far red 700-750 mμ. The blue and red band widths (50 mμ) were chosen because most of the action peaks in the light spectrum for

Figure 5. Mean spectral curves for unobscured light, 400 to 750 mμ, transmitted through coverings of FRP frost clear and and super clear panels and glass during twelve random periods between December 21, 1967 and June 22, 1968.

Figure 6. Percent unobscured insolation received under four covers on twelve random periods between December 21, 1967 and June 22, 1968.



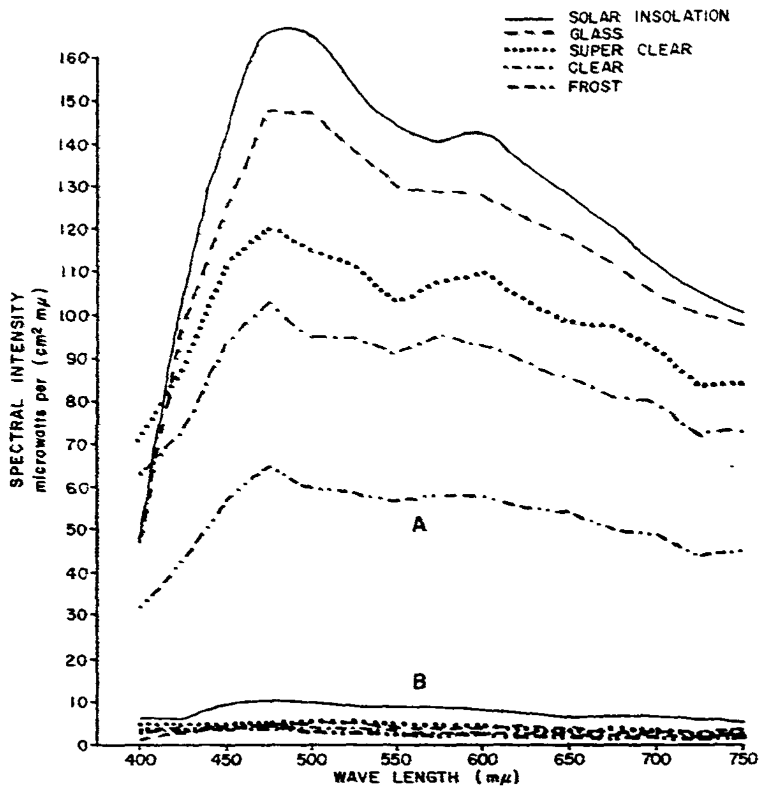
SOLAR INSOLATION
GLASS
FRP SUPER CLEAR
FRP CLEAR
FRP FROST
SPECTRAL INTENSITY
microwatts per (cm² mμ)
110
100
90
80
70
60
50
40
30
20
10
0
400
450
500
550
600
650
700
750
WAVE LENGTH (mμ)



GLASS
SUPER CLEAR
CLEAR
FROST
PERCENT ENERGY TRANSMITTED
100
90
80
400
450
500
550
600
650
700
750

Figure 7. Spectral intensity under four covers: A. May 13, 1968 an unobscured day and B. May 15, 1968 a day of total overcast

Figure 8. Mean spectral intensity bands of blue, green, red and far red light transmitted by coverings of FRP frost, clear and super clear and glass as compared to unobscured insolation during twelve random periods between December 21. 1967 and June 22, 1968.


SOLAR INSOLATION
GLASS
SUPER CLEAR
CLEAR
FROST
SPECTRAL INTENSITY
microwatts per (cm² mμ)
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
A
B
400
450
500
550
600
650
700
750
WAVE LENGTH (mμ)

photosynthesis and pigment absorption occur within these bands (14, 16, 33, 35, 42, 43, 54, 63). The green band (25 mμ) was arbitrarily chosen to encompass wave lengths within the green portion of the electromagnetic spectrum. The far red band (50 mμ) included wave lengths involved in the phytochrome system (29, 58). The mean spectral intensity of the measured wave lengths in each band was computed and is graphically compared in Figure 8.

Heat transmission

In Figure 9, the percent energy (BTU's) transmitted by the covering of each compartment is compared to the mean percentage of all wave lengths (400 to 1550 mμ) transmitted. A near linear relationship exists between the two sets of data with the frost covering transmitting the smallest percent of solar heat.

Plant temperatures The surface temperatures of red flowers and foliage grown under glass were significantly greater than under any other cover (Table 3). The temperatures of the red flowers grown under the frost cover were significantly lower than those under all other covers. The foliage temperatures under clear and super clear FRP panels were not significantly different but both were significantly greater than those under the frost treatment. Temperatures of foliage and red flowers were significantly greater under

Figure 9. Relationship of spectral intensity and solar energy:

A. Percent of mean solar spectral intensity, 400 to 1550 mμ, transmitted by four coverings during fifteen random periods between December 21, 1967 and June 22, 1968. The portion of the bar below the "divider lines" represent the percent energy in the visible spectrum (400-750 mμ).

B. Percent of mean solar BTU's received under four coverings during a 2 hour midday period for 88 days between September 30, 1967 and June 22, 1968.

Table 3. Mean surface temperature of black and white paper, red and white carnation flower heads and foliage under four coverings.

SURFACE TEMPERATURES F°						
COVER	BLACK SURFACE	WHITE SURFACE	RED FLOWER	WHITE FLOWER	FOLIAGE	AMBIENT AIR
FROST	97.6	76.9	78.6	74.0	68.2	INSIDE
CLEAR	106.2	79.4	82.7	76.1	69.1	68.1°F
S. CLEAR	108.8	79.5	81.5	74.5	69.4	OUTSIDE
GLASS	111.0[b]	82.9	87.8	77.1	71.3	59.3°F
OUTSIDE	107.8	67.9				
Q = HSD[a]	1.58	1.58	1.32	1.32	0.65	

[a] Tukey's honestly significant difference

[b] Due to limitation of instrument, reading is low

glass than those measured under all FRP covers. The temperatures of white flowers grown under glass and clear FRP were significantly greater than those measured under frost and super clear FRP but the pairs did not differ significantly. Only the foliage temperature under frost approached the inside ambient temperature.

Black and white surfaces The black and white surface temperatures, which simulated black and white body temperatures, were representative of incoming solar heat. There were significant differences between black surface temperatures under all covers, with those under glass the highest. White surface temperatures followed the same trend, but the clear and super clear surfaces were not significantly different (Table 3).

DISCUSSION

Red and white carnation varieties responded differently within and between each cover treatment. This indicates that specific environments would be required for each variety or clone in order to obtain maximum quality and production.

An important commercial cultural factor involves the number of vegetative breaks left on the plant at the time of disbudding.[1] All plants grown under FRP panels produced flowers with a weight-length ratio almost equal to the requirements for a fancy grade flower on the commercial market.[2] It is conceivable that in areas of high light and under FRP, a grower can always produce flowers of a fancy grade by removing two vegetative breaks and a standard grade by removing only one during disbudding procedures. Removal of two vegetative breaks from stems produced under glass would generally yield a standard grade flower.

Hasselkus and Beck (28) reported that anthesis of *Pelargonium hortorum* was delayed under decreased light intensity, due to low shelf location in a FRP covered area, but

---

[1]A standard procedure of removing lateral buds and excess vegetative breaks.

[2]Commercial market grades of carnations are: (a) fancy, a large unblemished flower with a 24 inch (60.9 cm) stem weighing 25 grams. (b) standard, an unblemished flower 20 inches (50.8 cm) and weighing 15 grams.

was comparable to growth under glass on higher shelves. In this portion of the investigation, decreased light intensity under the frost cover and high light transmitted through glass, produced similar results. Table 4 shows the peak production periods of red and white carnations grown under the four covers. Once again a varietal response occurred. The first production peak was comparable in all FRP coverings and fastest under glass. The light under all covers prior to the first peak was sufficient for photosynthetic activity during early stages of development. The second production peaks occurred during the lowest light period of the year thus accentuating peak and varietal differences under each cover. As a consequence no definite trend could be established.

The discoloration of the frost FRP cover due to aging, no doubt caused decreased production and rate of growth. Figure 10 compared the percentage of solar energy transmitted through the 42 month old frost FRP covering and a new frost panel. Approximately 8.2% more light (400-750 mμ) was transmitted through the new frost than through the old cover. Possibly the production rate of plant growth under the old frost treatment might have been equal to or better than glass if new frost FRP had been used. Such results would be in agreement with Holley et al. (32) who found that carnation plants grown under frost FRP and crystal clear PVC outproduced glass by 16 and 15 percent respectively during the first 65 weeks.

Table 4. Peak production periods for varieties of Pikes Peak white and CSU red carnations grown under four covers based on a three week moving mean from November 26, 1967 through June 23, 1968.

Weeks from planting to peaks of production

COVER	FIRST PEAK red	FIRST PEAK white	SECOND PEAK red	SECOND PEAK white
FROST	23	21	45	34
CLEAR	25	23	38	39
S. CLEAR	25	25	33	40
GLASS	21	21	35	46

planting date: July 18, 1967

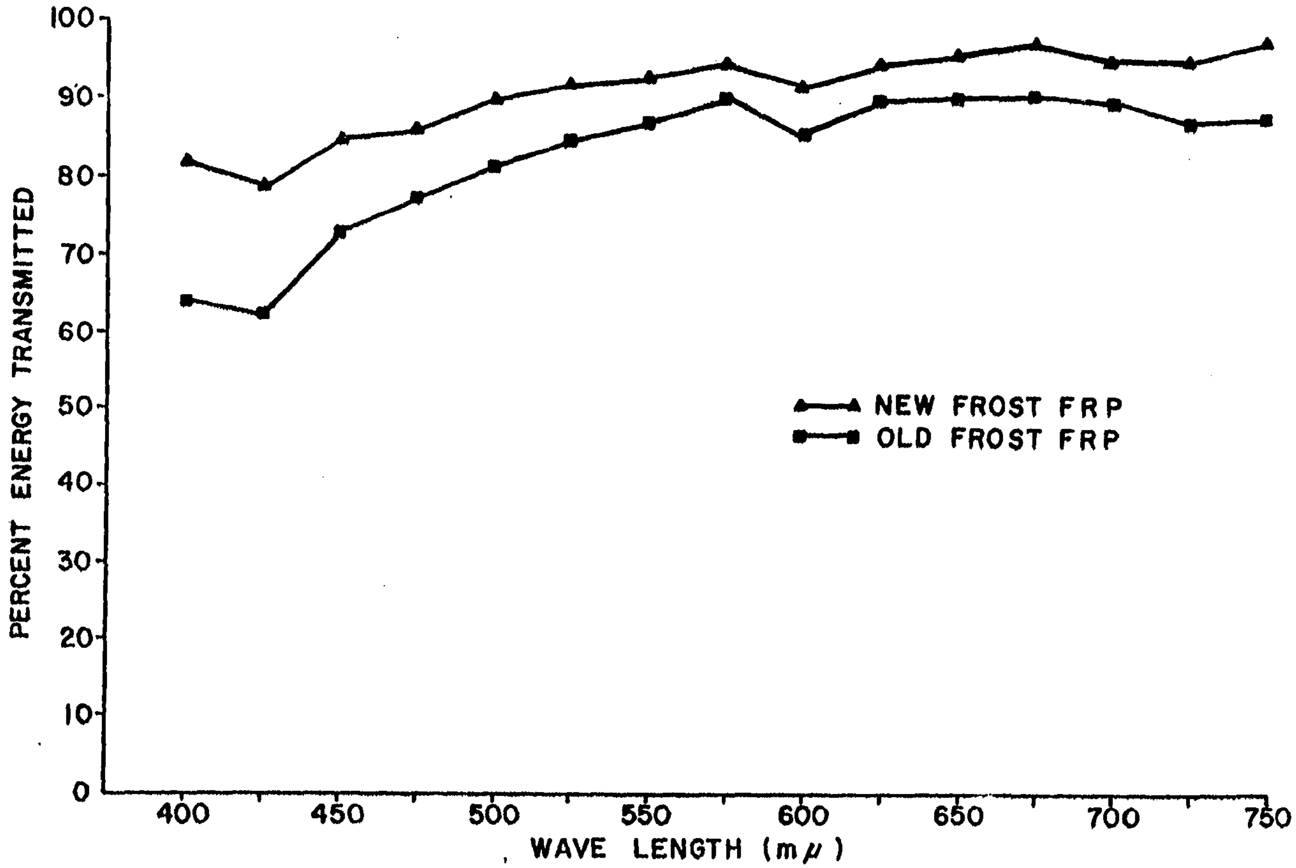


Figure 10. Percent of insolation transmitted by four year old and new panels of FRP frost.

The spectral transmission characteristics of each covering were similar in that there was little difference in the ratios of blue, green, red, and far red intensities. Table 5 indicates the ratios of incoming light to that transmitted through the four covers and a visual illustration of this can be seen in Figure 8. The data were from 12 random unobscured days and were not representative of periods with various cloud types and abnormal atmospheric conditions that occurred during the investigation.

The energy present in each band of wave lengths (Figure 8) is shown in Table 6. It can be postulated that the ratios of the energy in the green, blue and red wave length bands may determine the rate and degree of plant growth. However, in this part of the investigation the band energy ratios of all covers were similar. For this reason the resulting growth responses are attributed in part to the total energy received in each compartment. The mean total energy received under the frost cover was too low for adequate photosynthetic activity and growth was retarded.

The differences in light intensity received through each cover was apparently a major controlling factor in plant response. Blackman (4) and Burkholder (8) found that plant growth accelerated as intensity increased until light saturation was reached. In this part of the investigation, all covers, except frost FRP, evidently provided adequate light

Table 5. Ratios of incoming blue, green, red and far red unobscured light compared to the same wave length regions transmitted by glass and FRP frost, clear and super clear panels. Twelve random samples on days between December 21, 1967 and June 22, 1968.

	INTENSITY RATIOS			
COVER	BLUE:GREEN	BLUE:RED	GREEN:RED	RED:FAR RED
FROST	1 : 1.27	1 : 1.23	1 : 0.97	1 : 0.89
CLEAR	1 : 1.15	1 : 1.09	1 : 0.94	1 : 0.87
S.CLEAR	1 : 1.14	1 : 1.04	1 : 0.91	1 : 0.85
GLASS	1 : 1.12	1 : 1.00	1 : 0.89	1 : 0.84
SOLAR	1 : 0.91	1 : 0.98	1 : 0.89	1 : 0.83

Table 6. Mean energy of blue, green, red and far red bands of wave lengths transmitted by coverings of FRP frost, clear and super clear and glass as compared to unobscured insolation during twelve random periods between December 21, 1967 and June 22, 1968.

ENERGY RECEIVED[a] - ergs per sec per cm^2

	BLUE (425-475 mμ)	GREEN (525-550 mμ)	RED (625-675 mμ)	FAR RED (700-750 mμ)	SUM OF BANDS
FROST	157.80	100.45	194.25	174.30	626.80
CLEAR	240.35	139.13	263.65	229.70	872.83
S. CLEAR	287.75	164.03	301.00	257.50	1010.28
GLASS	344.50	193.23	344.50	290.75	1172.98
OUTSIDE	436.25	239.72	428.85	359.15	1463.97

[a]All numbers x 10^2

intensity and perhaps the plants reached light saturation. Each cover created a different light intensity and plant growth differed accordingly. The differences in response to light intensity of red and white varieties tend to substantiate the work of Holley (30), who found that the relative growth rates of three carnation varieties varied according to the seasonal light intensity. During months of high light, the carnation growth rates were similar and during winter months, the growth rates of the same varieties were considerably different.

New fiberglass reinforced plastic panels in greenhouses accumulate condensate on the underside and excessive dripping occurs. After one or two years the surface tension and/or adhesion qualities change and the droplets are less evident. The super clear cover permitted considerable condensate during the investigation so spectral transmission characteristics were determined with and without condensate. A preliminary study on the effect of condensate on super clear FRP indicates that a decrease in the mean intensity between 400 and 750 mμ of about 8 percent. The intensity ratios of different wave lengths were not appreciably altered.

Another possible factor contributing to decreased growth and production under glass was the effect of light intensity on transpiration. Rackham (56) noted that transpiration of _Impatiens parviflora_ increased with increasing light intensity but was not linearly proportional. Burkholder (7) summarized the work of several workers noting a direct effect of radiation on transpiration, depending on the evaporating power of the air. It can be postulated that radiation transmitted through coverings of glass, which is greater than through FRP, increases leaf temperature and the absorbing power of the air surrounding plants and thus increases transpiration. The water loss exceeded uptake, creating a water deficiency and reduced plant growth.

SUMMARY

In general the environment created by the covering of FRP super clear enhanced plant growth more than the environments created by glass and panels of clear and frost FRP. Plant responses and environmental conditions include:

1. More flowers of both red and white were produced under the super clear FRP covering than under any other covering. The least flowers were produced under frost. Production of flowers under glass and under FRP clear was comparable.

   The lightest weight red flowers with the shortest stems were produced under glass. The weights of white flowers produced in all covers were not significantly different. The shortest stemmed white flowers were produced under glass.

   There were no significant treatment differences in the biweekly production of first vegetative breaks or in their weights.

2. The surface temperatures of black and white paper, red flowers and plant foliage were significantly warmer under glass and cooler under FRP frost than under any other cover. White flower surface temperatures under glass did not differ significantly from those under the clear FRP treatment.

3. A decreasing percentage of solar heat was transmitted by the coverings of glass and panels of FRP super clear, clear and frost respectively.
4. The mean intensity of transmitted wave lengths between 400 and 1550 mμ was lowest under frost FRP cover and increased progressively under clear and super clear FRP covers and glass.
5. Small differences occurred between the ratios of blue, green, red and far red bands of light transmitted by each covering. The intensities of all bands decreased progressively under the glass cover and FRP super clear, clear and frost coverings respectively.
6. The mean spectral curve transmitted by each covering on cloudless days was comparable in wave length distribution, but varied in intensity. On days of total overcast the transmission characteristics under all coverings were basically equal in distribution and intensity.

PART II

GROWTH RESPONSES OF PLANTS TO INSOLATION TRANSMITTED BY TINTED PANELS OF FIBERGLASS REINFORCED PLASTIC

METHODS AND MATERIALS

Chamber Construction

Covering development

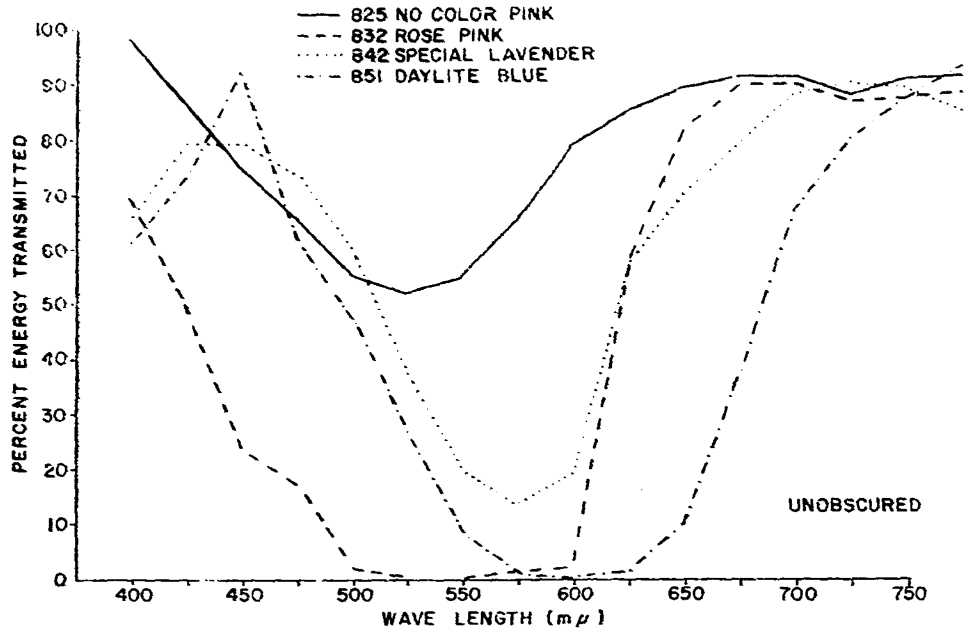
Colored samples of five ounce greenhouse grade FRP panels and other colored, nearly transparent materials such as overhead projector transparencies and filters for theatrical lighting were compared for spectral transmittancy with the ISCO model SR and SRR Spectroradiometer. Forty-four Roscolene filter samples produced by Rosco Laboratories, Inc., Harrison, N.Y. were evaluated visually for color, density and general sunlight transmission. Nineteen samples within the blue, violet and red ranges were chosen for further analysis.

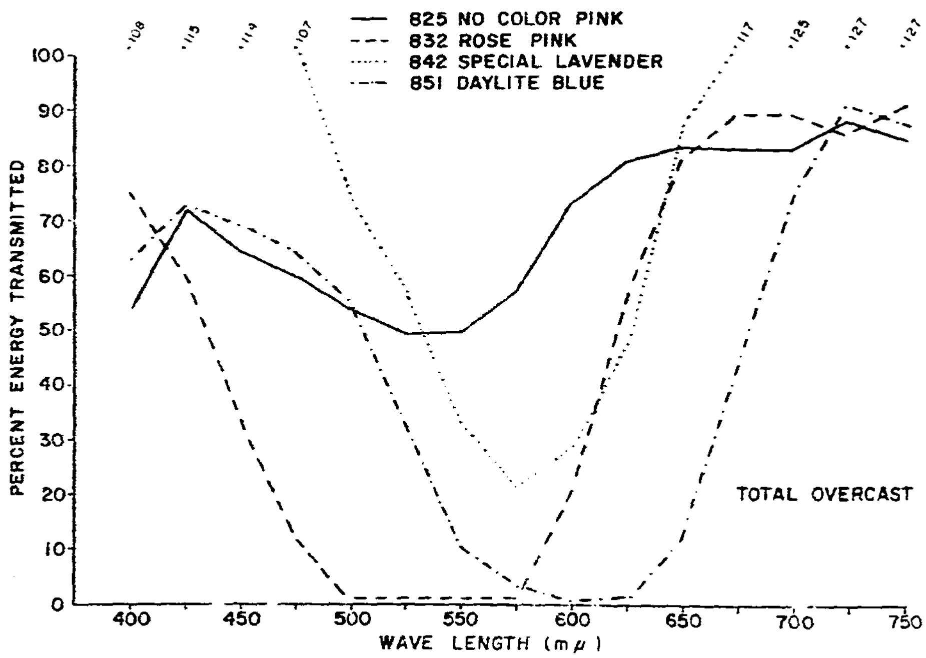
Spectral analysis   Spectral analyses were made using insolation as the light source on April 8 and 9, 1968. April 8 provided a spectrum with unobscured solar insolation and April 9, a uniform cloud cover. The target of the sensing element was placed perpendicular to the horizon so both diffuse and direct radiation would be analyzed. All readings were taken between the hours of 10:00 a.m. and 2:00 p.m. Mountain Standard Time, when the sun was at an angle no greater than 33^{o} to the samples.

Filter selection   From the nineteen Roscolene filter samples analyzed four were chosen for replication in fiberglass reinforced plastic panels. Figures 11 and 12 show the spectral

Figure 11. Spectral transmission characteristics of four specific Roscolene plastic samples during a period of unobscured insolation. April 9, 1968.

Figure 12. Spectral transmission characteristics of four specific Roscolene plastic samples during a period of overcast. April 8, 1968.


825 NO COLOR PINK
832 ROSE PINK
842 SPECIAL LAVENDER
851 DAYLITE BLUE
PERCENT ENERGY TRANSMITTED
WAVE LENGTH (mμ)
UNOBSCURED


825 NO COLOR PINK
832 ROSE PINK
842 SPECIAL LAVENDER
851 DAYLITE BLUE
PERCENT ENERGY TRANSMITTED
WAVE LENGTH (mμ)
TOTAL OVERCAST

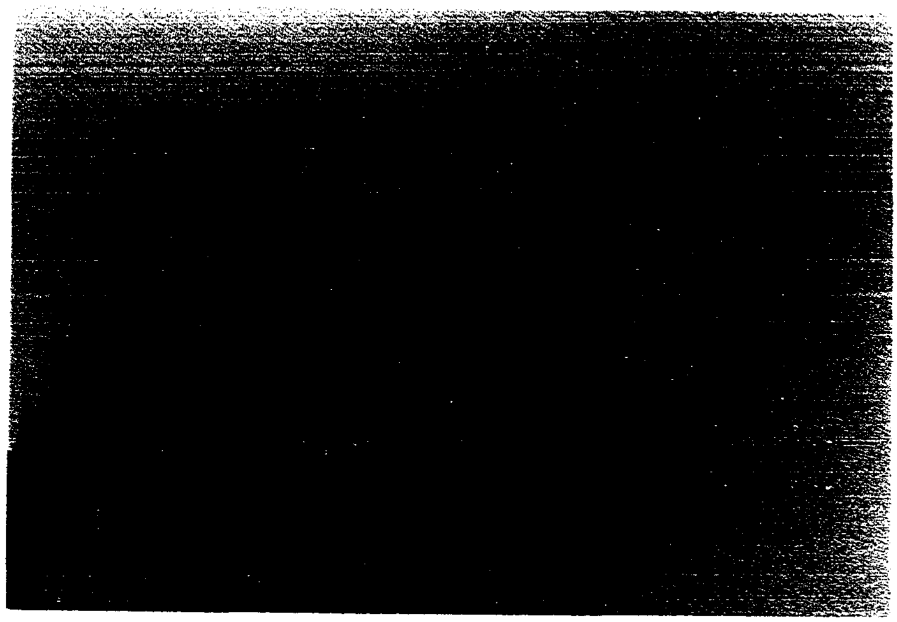
transmission characteristics of the samples within the visible region on an unobscured and totally overcast day. The spectral transmission characteristics between 400 and 1550 mμ of all nineteen Roscolene samples are shown in Appendix B.

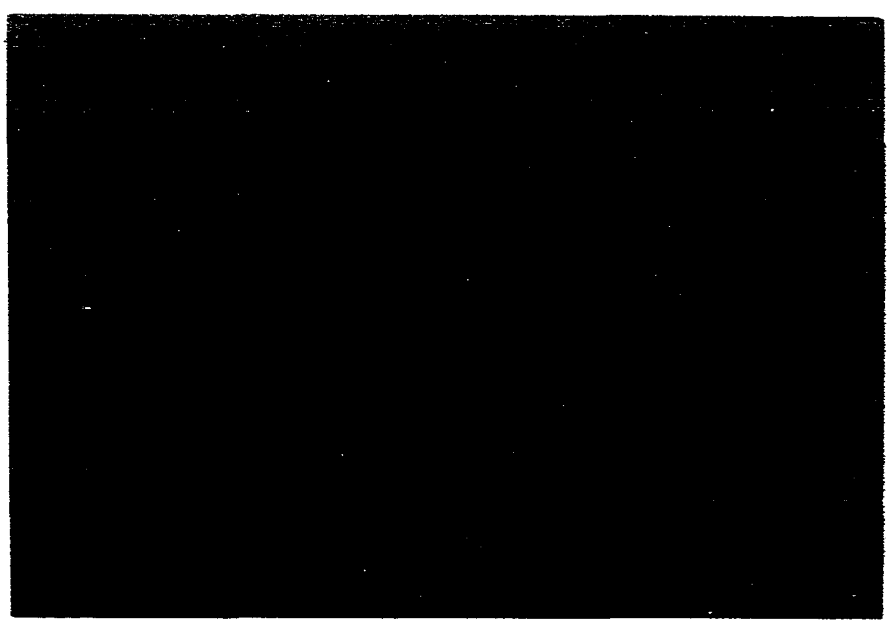
The blue and magenta filters were chosen to provide decreased intensities in both ends of the transmitted spectrum. The pink filter provided transmission characteristics comparable to the photosynthetic action spectrum described by Hoover (33). The intensities of blue and red transmitted through the violet filter were nearly equal, and almost 80 percent greater than the green portion. The four selected filters are shown in Figure 13.

Fiberglass reinforced plastic color samples. The four Roscolene color samples chosen for replication in FRP laboratory samples were sent to major FRP panel producers. Three FRP panel manufacturers, Lasco Industries, Montebello, California; Filon Corporation, Hawthorne, California; and Structoglas Incorporated, Argo, Illinois made 6 inch by 6 inch laboratory samples duplicating the color and spectral transmission characteristics of the Roscolene "base" colors as close as possible. They also provided additional laboratory samples, one hue lighter and one hue darker than each of the base colors. The same criteria used in evaluating the Roscolene filters applied to the selection of the most desirable laboratory samples. The four samples are shown in Figure 14.

Figure 13. Four Roscolene filters selected for duplication into FRP laboratory samples. Clockwise: 832-rose pink, 851-daylight blue, 825-no color pink and 842-special lavender.

Figure 14. Four FRP laboratory samples selected for duplication into corrugated FRP panels. Clockwise: blue, violet, pink and magenta.





Spectral analysis of the "base" samples and darker and lighter hues were made on June 27, 1968 (Figures 15a, 15b, 15c and 15d). The spectral transmission characteristics of the remaining samples are shown in Appendix B. After analysis, the companies were requested to produce 60 sq. ft. of the designated laboratory samples in 5 oz., 2½" corrugated panels for use as chamber coverings.

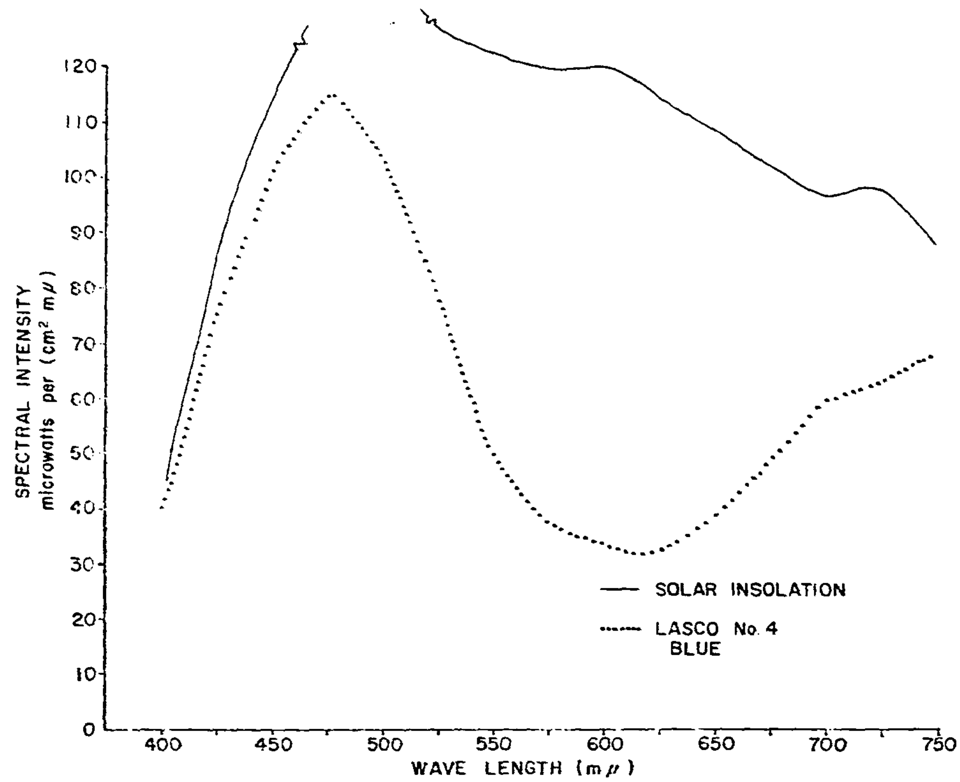
Chamber design

Six chambers, each containing 97.5 cubic feet of space and 24.0 sq. ft. of floor area, were constructed in the south half of the Colorado State University floriculture research wind tunnel (Figure 16). The quonset shaped wind tunnel, oriented east and west, provided maximum solar radiation within each chamber. Each chamber was separated by a plywood wall attached to the steel pipe framework of the wind tunnel. All chamber surfaces were painted white inside and out before the coverings were attached.

Cooling and heating system Each chamber had an independent cooling and heating system. Positive cooling was accomplished with a two speed 6500/4300 CFM, evaporative cooler. A duct system carried the air from the cooler through a plastic distribution tube in a plenum under the floor of the chambers (Figures 17 and 18). When any one chamber required cooling, the evaporative cooler, chamber damper and exhaust fan were energized (Figure 18).

Figure 15a. Spectral transmission curve of a colored FRP laboratory sample selected for duplication-Lasco no. 4, blue.

Figure 15b. Spectral transmission curve of a colored FRP laboratory sample selected for duplication-Lasco no. 7, magenta.


SPECTRAL INTENSITY
microwatts per (cm² mμ)
120
110
100
90
80
70
60
50
40
30
20
10
0
400
450
500
550
600
650
700
750
WAVE LENGTH (mμ)
SOLAR INSOLATION
LASCO No. 4
BLUE

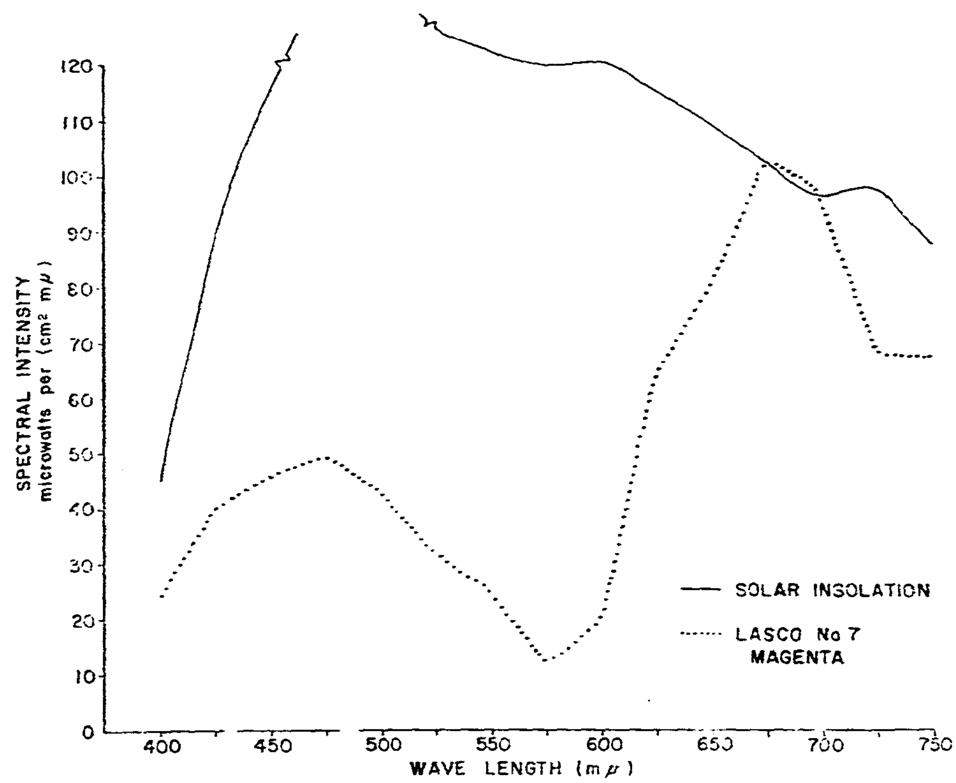
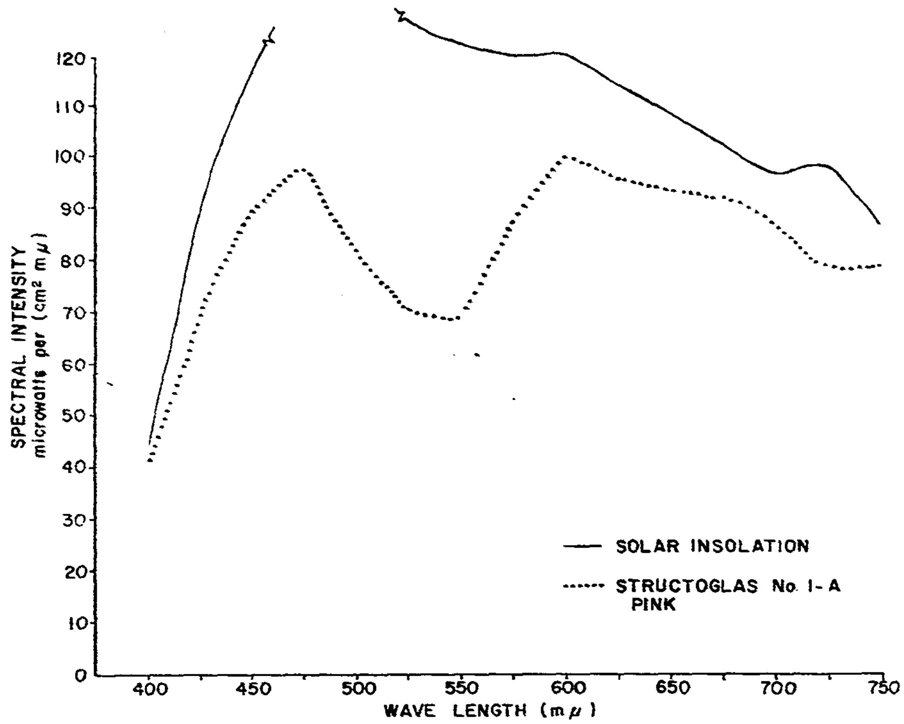
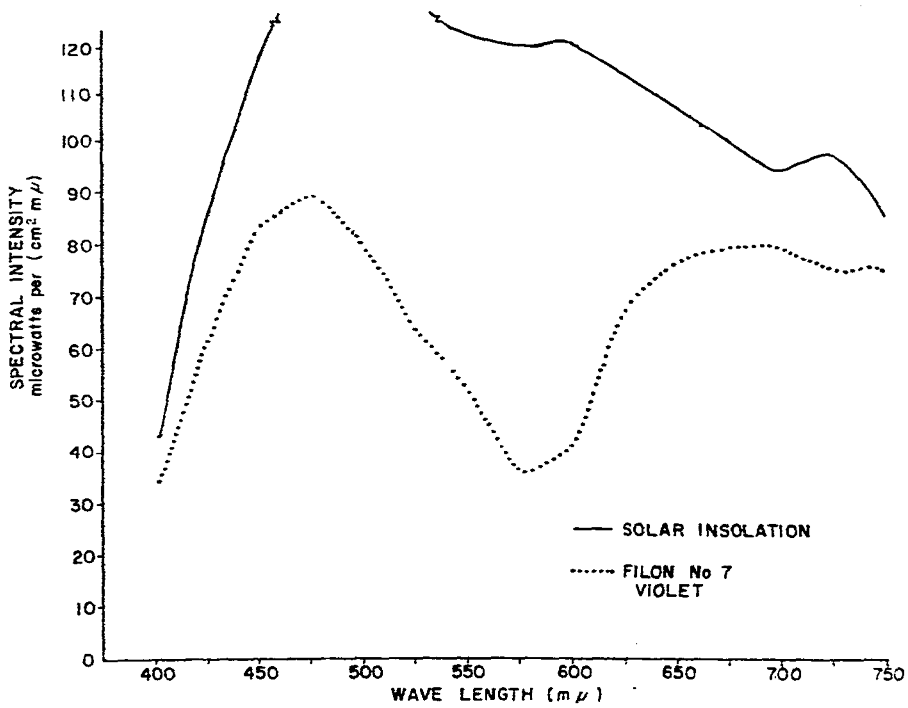

SPECTRAL INTENSITY
microwatts per (cm² mμ)
120
110
100
90
80
70
60
50
40
30
20
10
0
400
450
500
550
600
650
700
750
WAVE LENGTH (mμ)
SOLAR INSOLATION
LASCO No 7
MAGENTA

Figure 15c. Spectral transmission curve of a colored FRP laboratory sample selected for duplication - Structoglas no. 1-A, pink.

Figure 15d. Spectral transmission curve of a colored FRP laboratory sample selected for duplication - Filon no. 7, violet.


SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)
SOLAR INSOLATION
STRUCTOGLAS No. I-A
PINK


SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)
SOLAR INSOLATION
FILON No 7
VIOLET

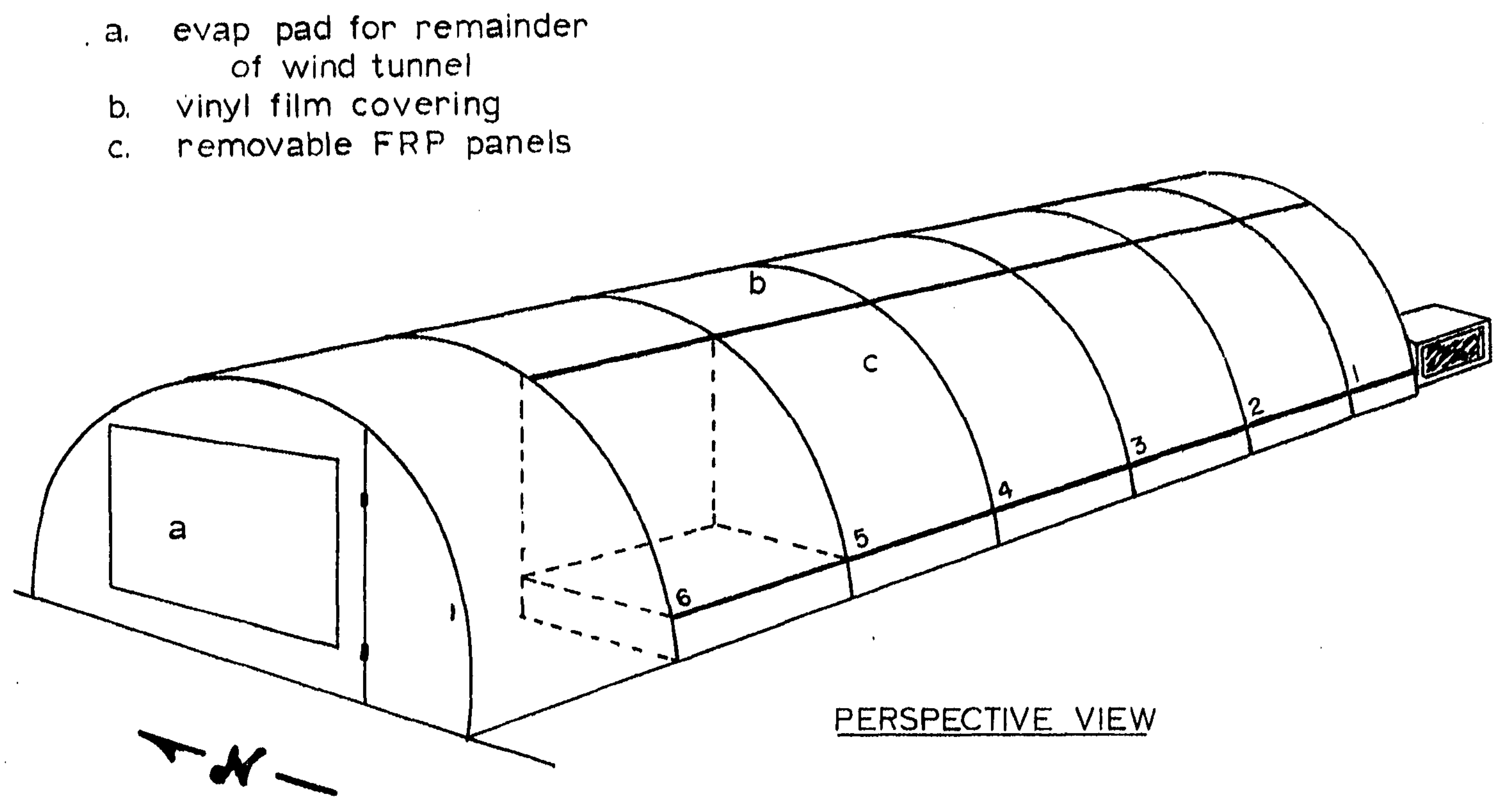
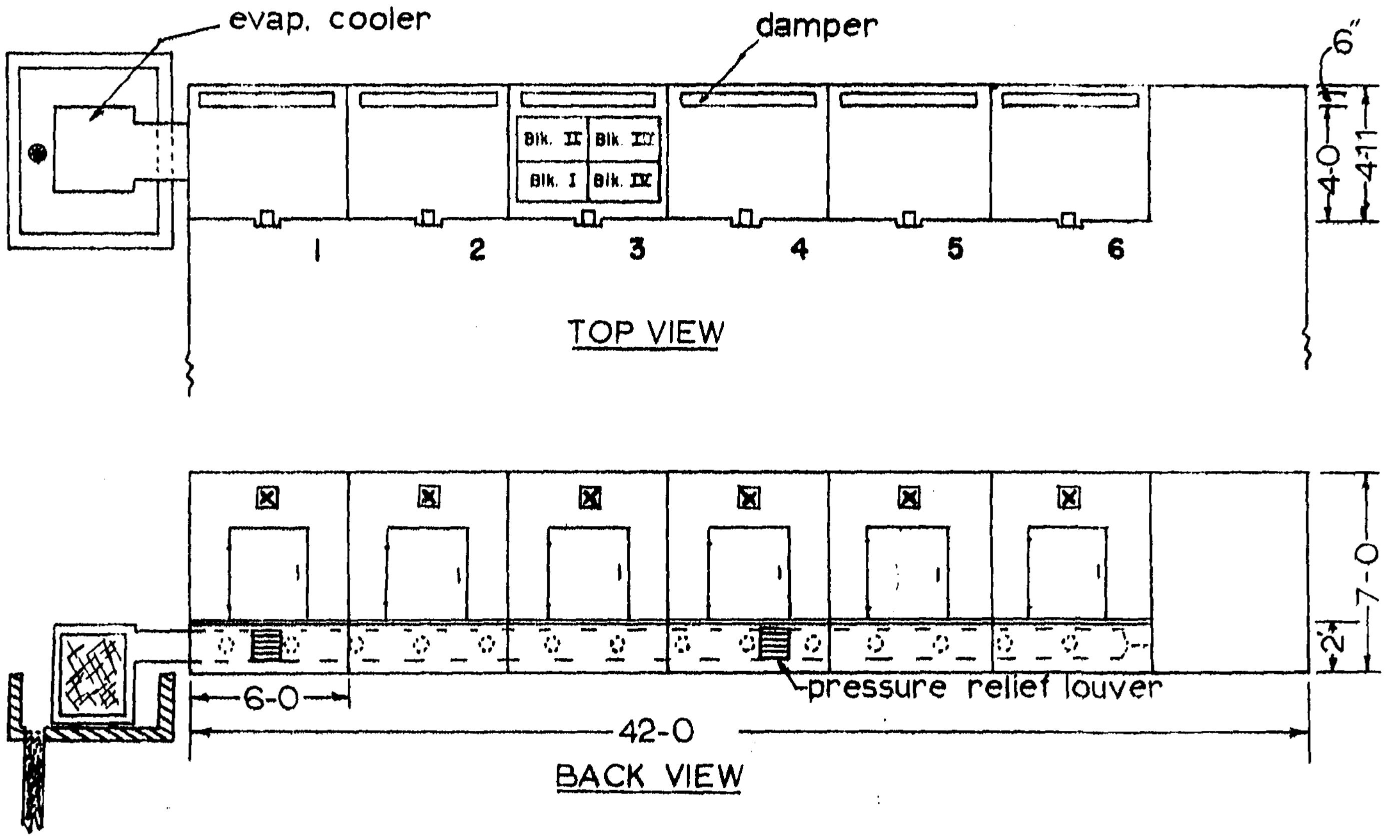


Figure 16. Perspective view of Colorado State University wind tunnel and spectral transmission chamber location.



scale: 3/16" = 1'

Figure 17. Detailed drawing of top and back views of spectral transmission chambers.

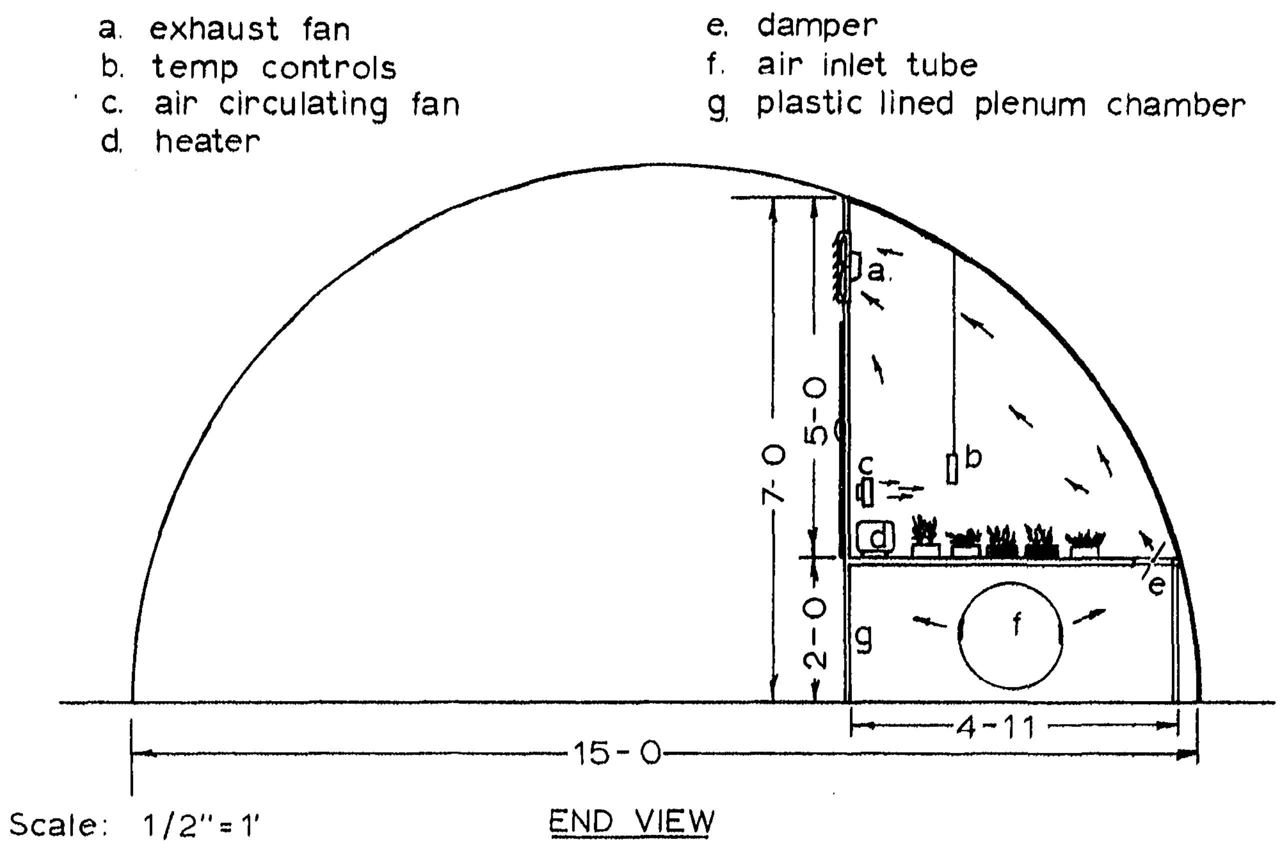


Figure 18. End view of single chamber showing environmental controls system.

Each chamber was electrically heated. A small fan in the heater provided rapid and uniform heating capabilities during periods of operation.

Specifications of the equipment used in the facilities are presented in Appendix B.

Temperature control Each compartment was controlled by thermostats (Figure 19) placed in a venturi pipe. A specific temperature rating was preset in each thermostat at the factory. A small fan was used to maintain a constant air flow across the thermostats and prevent air stratification in the chamber.

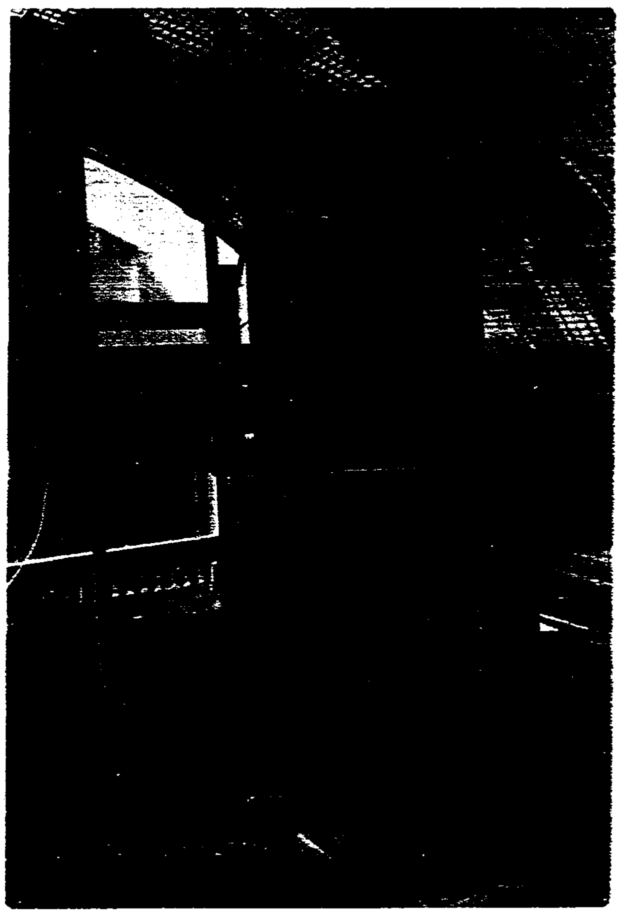
A control panel was designed to provide maximum versatility of the thermostat system consisting of five temperature loads and 8 different temperature combinations (Figure 20). A Bryant photoelectric control was used to automatically change the temperatures to day and night settings.

The two speed evaporative cooler fan was controlled by two separate thermostats in each chamber. The second speed was controlled by a thermostat set 2 degrees warmer than the initial cooling requirement. The water pump was energized by a thermostat when the outside air temperature reached 60°F or with a bypass switch on the control panel.

Covering Each chamber was covered with five ounce per square foot fiberglass reinforced plastic panels. Greenhouse grades of super clear and new frost white, were

Figure 19. Factory preset thermometer type thermostat used to maintain heating and cooling requirements.

Figure 20. Temperature control console with solar energy recording equipment.



installed on chambers 2 and 5. The four tinted FRP panels were used to cover the remaining four chambers; violet-1, pink-3, blue-4, and red-6. The covering was the only intended treatment throughout the investigation.

Temperatures

This investigation involved all "warm temperature" type plants, thus a minimum of 60°F was maintained, night and day. The following data shows the temperature regime used for all experiments.

	Low Alarm	Second Fan	Heat	Cool	High Alarm
Night	57°	64°	60°	62°	67°
Day	57	73	60	71	75

The measured temperatures for heating and cooling varied ±2°F.

Humidity

The relative humidity of the incoming air varied between 8 and 70 percent. During daylight hours and periods of no ventilation the relative humidity was approximately 60 percent.

Growing media

All plants were grown in a soil mixture of 2 Fort Collins loam, 1 Canadian peat and 1 river sand by volume in 6" plastic containers. The growing media had the following nutrient concentrations at planting and harvest times:

	ppm				Total Salts (Millimhos/cm)	pH
	NO_3	P	K	Ca		
Before planting	10	½	5	100	27	6.8
At harvest	25	1½	10	200	40	7.4

Watering and nutrition

When the soil surface was slightly damp to the touch, the pot was watered. Depending on plant size, each pot was watered at least once every day.

Nutrients were automatically supplied at each watering. The following nutrient concentrations were injected with a Smith model R-8 fertilizer injector at a 1:200 rate:

ppm per 1000 gallons of irrigation water			
K	223	N	206
Ca	20	Na	8
Mg	29	P	64
B	10		

Carbon dioxide concentration

Carbon dioxide concentrations were analyzed periodically during the investigation with a Beckman 15-A infrared analyzer. During periods of ventilation the concentrations varied from 270 to 325 ppm. During periods of no ventilation the concentration never dropped lower than 240 ppm during daylight hours. It remained below 700 ppm at night.

Light

Solar radiation was the sole source of light and the spectrum transmitted by the six coverings was the only intended variable.

Plant Materials

Plants from three families; Compositae, Leguminosae and Solanaceae were used to evaluate the effects of spectral transmission on plant growth.

Tagetes patula, a French Marigold, was used to observe the effects of spectral transmission on rate of flowering, branching habit, and flower development. Seed of the variety Petite Orange (Y-934) was obtained from the Rocky Mountain Seed Company, Denver, Colorado.

Phaseolus vulgaris, pinto bean, was used for growth rate evaluations. Hybrid seed, University of Idaho No. III, Lot 6195 was obtained from the Longmont Seed Company, Longmont, Colorado.

Lycopersicon esculentum was used to evaluate both flower development and growth rates. Hybrid tomato seed, variety Fireball No. II was obtained from the Colorado State University seed stock of Dr. R. L. Foskett.

Experimental Design

The investigation involved six treatments. Two of the treatments, frost and super clear FRP, were considered as controls. The remaining treatments were the specifically colored FRP panels. Galvanized tin trays were used to divide each chamber into four blocks (replications). Plants placed in each block were rotated every four to five days within that block (Figure 17).

All spectral, radiation and temperature data were analyzed and correlated statistically and graphically as described in Part I Materials and Methods.

Measurements

Transmission

All spectral and heat transmission measurements were taken between 10:00 a.m. and 2:00 p.m. Mountain Standard Time. A pyranometer described in part I was placed in the center of each chamber at plant height to sense heat transmission. Radiation reaching the coverings was measured with a pyranometer mounted on top of the Spectral Transmission Laboratory.

The solar spectrum transmitted through each covering was measured with the recording spectroradiometer described in part I. Transmission characteristics inside and outside the chambers were measured periodically from November 20, 1968 to January 20, 1969.

Temperatures

Plant temperatures were evaluated by measuring the leaf surface temperatures of tomato with the Barnes pyrometer also described in part I. The surface temperatures of black and white bodies were also recorded in all compartments and outside.

Plants

Tomato plant development   Seed of Fireball number II were planted in a flat of steam sterilized media composed of 1/3 soil; 1/3 sand and 1/3 peat by volume on October 28, 1968. The seed flats were placed under intermittent mist and allowed to germinate. On November 12, 1968 the seedlings were transplanted into 6" plastic pots. The plants, five per pot, were developing the first true leaves when transplanted. The plants were allowed to grow for forty days, then a pot from each block was evaluated, measured and harvested. Additional pots were harvested and data taken at intervals of 50, 60, and 70 days from transplanting. Data taken included fresh and dry weights, leaf and flower bud or flower development, stem size, and total height. A gauge with a scale of values, ranging from 4 (0.4 cm) to 12 (0.9 cm) was used to measure the stem size of tomatoes.

Tomato plant growth rate   Seed of Fireball number II were germinated in the same manner described in the previous experiment. Seedlings were transplanted into 6" pots, three per pot, on November 23, 1968. Each block contained 6 pots or 24 per chamber. Two pots of plants from each block were harvested 21 days after transplanting. The remaining plants were harvested 42 days and 63 days after transplanting. Measurements taken included: total height, first through fourth internodes, widths of the terminal blade of the second and fourth true leaves, number of leaves, development and fresh and dry weights. Development criteria and values for both tomato experiments were as follows:

1. No visible buds
2. Buds visible and separated
3. Buds large, no color
4. Buds opening
5. Buds full open
6. One or more fruit smaller than ½ cm in diameter
7. One or more fruit over ½ cm in diameter.

Flower development of French marigolds   Seed of Petite Orange were planted October 28, 1968, and germinated in the same manner as described in the tomato experiment. On November 12, 1968, six seedlings, with the first true leaves showing, were transplanted in 6" plastic pots. Each block contained three pots for continuous observations of flower development. Sixty-two days after the transplanting date, the plants were harvested. The data included total height, number of breaks, total flowers and fresh and dry weights.

Development rate of Pinto bean plants   Pinto bean seed were soaked in water from 10-18 hours and then sown in a flat containing a mixture of 1/3 Canadian peat and 2/3 horticultural perlite. The seedling flats were placed in a germination chamber maintained at 78°F, 60 percent relative humidity and 10 foot candles of light from an incandescent lamp. Upon emergence of the hypocotyl the flats were placed in a 60°F greenhouse with 70 percent humidity and full light.

Transplanting took place six days after soaking the seed, just as the hypocotyl straightened and the plumule started to emerge.

The beans in the first replication were soaked on November 13, 1968 and transplanted November 19, 1968. They were evaluated and harvested fourteen days later, December 3, 1968. The following schedule shows the dates of soaking, transplanting and harvesting:

	Soak and Sow	Transplant	Harvest
Replication 1	November 14	November 19	December 3
Replication 2	November 25	December 3	December 17
Replication 3	December 10	December 17	December 31
Replication 4	December 23	December 31	January 14

Factors observed at harvest   Development - The stage of growth achieved during the fourteen day period. The following criteria and values were used to evaluate development:

<u>Value</u>

1	No three leaflet leaf visible
2	First three leaflet leaf opening
3	First three leaflet leaves ½-1 cm wide
4	First three leaflet leaves over 1 cm wide
5	Second three leaflet leaf visible
6	Second three leaflet leaf opening
7	Second three leaflet leaves ¼-½ cm wide
8	Third three leaflet leaf visible

Other observations included total plant height from the top of the pot, length of internode between cotyledons and first true leaves (first internode) and the length of the second and third internodes.

RESULTS

Plant Responses

Tomato plant development

Buds and fruit No significant differences occurred in the bud development of first and second clusters on plants grown in the chambers covered with FRP panels of super clear, pink, frost or violet (Table 7). Bud development under both the super clear and pink treatments was significantly greater than under the blue and magenta treatments (Figure 21). Plants in the super clear and pink treatment also had the first and most fruit set and largest fruit at harvest.

Total height The plants grown in the magenta treatment were significantly taller than those grown in the blue and frost treatments (Table 7).

Fresh and dry weight Plants with the greatest fresh weight production were from the super clear, pink and frost treatments respectively and the least production from the blue treatment. Only the super clear and blue treatments differed significantly. There were no significant differences in dry weight between treatments (Figure 22).

Leaf development There were no significant differences in the number of true leaves produced by the plants under the various treatments. Treatments of super clear, pink

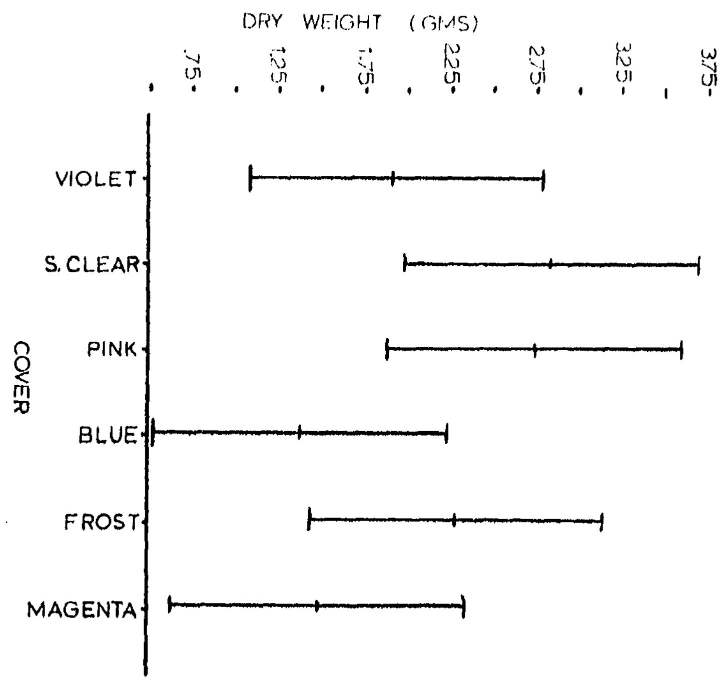
Table 7. Mean developmental responses of Fireball II tomato plants grown under six FRP cover treatments and harvested 50, 60, 70 and 80 days after planting.

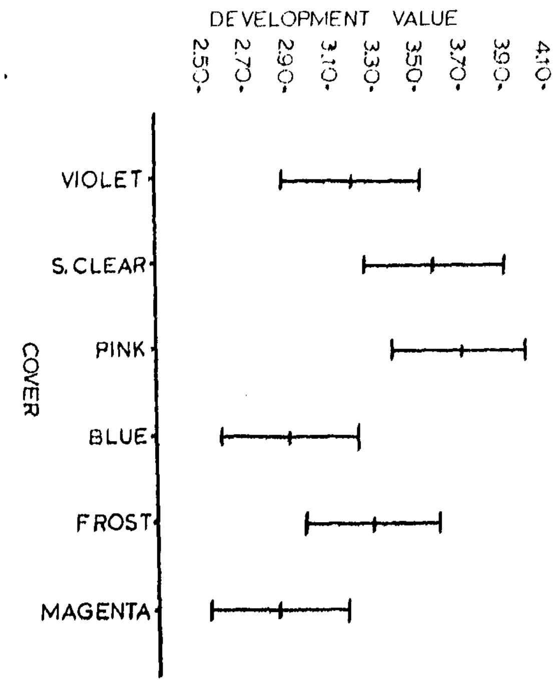
TOMATO DEVELOPMENT							
COVER	BUD DEVELOPMENT[b]		VISIBLE	TOTAL	WEIGHT (gms)		STEM SIZE[b]
	CLUSTER-1	CLUSTER-2	TRUE LEAVES	HEIGHT (cm)	FRESH	DRY	
VIOLET	3.19	2.22	9.42	25.43	19.98	1.93	5.59
S. CLEAR	3.57	2.75	10.00	27.27	25.55	2.84	6.01
PINK	3.70	2.69	9.89	28.23	24.99	2.75	5.75
BLUE	2.91	2.00	9.05	23.95	15.19	1.38	4.61
FROST	3.30	2.27	9.61	22.99	20.74	2.29	6.11
MAGENTA	2.86	1.81	9.51	28.62	17.49	1.51	4.86
Q=HSD[a]	0.64	0.62	0.96	3.64	8.07	1.71	1.12

[a]Tukey's honestly significant difference
[b]Defined values,- see materials and methods

Figure 21. Confidence intervals (95 percent) showing the mean development value of buds, flowers and fruit on plants of Fireball II tomatoes planted November 12, 1968 and harvested 50, 60, 70 and 80 days later. A value of 4.00 equals fruit less than 1/2 cm in diameter and 3.00 equals buds swelling but not open.

Figure 22. Confidence intervals (95 percent) showing the mean dry weight production of Fireball II tomato plants harvested 50, 60, 70 and 80 days after planting.


DRY WEIGHT (GMS)
.75
1.25
1.75
2.25
2.75
3.25
3.75
VIOLET
S. CLEAR
PINK
BLUE
FROST
MAGENTA
COVER


DEVELOPMENT VALUE
2.50
2.70
2.90
3.10
3.30
3.50
3.70
3.90
4.10
VIOLET
S. CLEAR
PINK
BLUE
FROST
MAGENTA
COVER

and frost produced plants with the greatest number of true leaves (Table 7).

Stem size The diameters of the stems produced in the frost and super clear treatments were significantly larger than those grown in the magenta and blue treatment. Stem diameters in frost, super clear and pink treatments did not differ significantly (Table 7).

Tomato plant growth rate

Total height Plants grown under the super clear treatment were taller than all other treatments 21 weeks after planting but, the plants grown under the magenta treatment were significantly taller during the total investigation. The frost treatment yielded the shortest plants which did not differ significantly from plant height under the violet and blue treatments (Table 8).

Bud development Flower buds in the super clear treatment developed significantly faster than those in all other treatments except the frost. Bud development in the pink treatment did not differ significantly from the frost treatment and the slowness of flower development under the magenta treatment was highly significant.

Fresh weight production The fresh weight of plants harvested from the super clear treatment was consistently and significantly heavier (Table 8). The fresh weight production

Table 8. Mean growth rate characteristics of Fireball II tomato plants grown under six FRP panel covers and harvested 3, 6, and 9 weeks after planting.

TOMATO PLANT GROWTH RATE									
COVER	TOTAL HT (cm)	INTERNODES (cm)		BUD DEVELOPMENT[b]	LEAF WIDTH (cm)		WEIGHT (gms)		NUMBER OF LEAVES
		FIRST	FOURTH		SECOND	FOURTH	FRESH	DRY	
VIOLET	19.39	2.39	1.94	2.24	2.04	2.47	18.03	1.64	7.33
S. CLEAR	22.21	2.20	2.27	2.65	2.42	2.54	26.00	2.33	8.15
PINK	20.94	2.37	1.91	2.36	2.17	2.39	20.63	1.80	7.87
BLUE	20.46	3.09	1.76	2.23	2.05	2.25	15.34	1.38	7.44
FROST	18.78	2.19	1.95	2.39	2.05	2.26	20.90	2.01	7.62
MAGENTA	23.35	3.88	1.90	1.98	2.26	2.39	15.52	1.44	7.82
Q = H S D[a]	2.12	0.24	0.32	0.27	0.25	0.22	4.41	0.63	0.47

[a] Tukey's honestly significant difference

[b] Defined value,- see materials and methods

under the magenta and blue treatments was significantly lower than the production under the super clear, pink or frost treatments during the 21 week growing period.

Dry weight The trend in dry weight production was similar to that of fresh weight. There were no significant differences in dry weights of plants grown under the super clear, frost and pink treatments (Figure 23).

Other responses Table 8 shows the responses of internode length, leaf widths and leaf development. The first internode, between cotyledon and first true leaf, was significantly longer in the magenta treatment than in all others. The super clear treatment tended to be most responsive in the remaining categories, but not significantly.

Flower development of French marigolds

The growth responses of the marigold to the various cover treatments were similar to those of the tomato except in plant height (Table 9). The total height of plants grown in the blue treatment was significantly greater than all other treatments and those grown in the frost, pink and super clear treatments were the shortest.

Rate of flowering The number of days required for the opening of the first flower was significantly less for the super clear treatment than in all others except the pink. Plants in blue treatment were slowest and highly significant when compared to all other treatments (Figure 24).

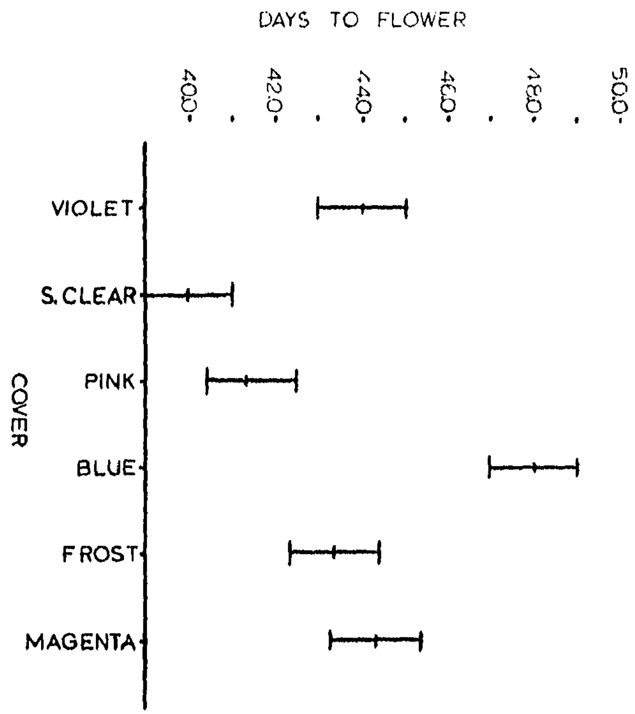
Table 9. Flowering responses of French marigolds grown under six FRP panel covers.

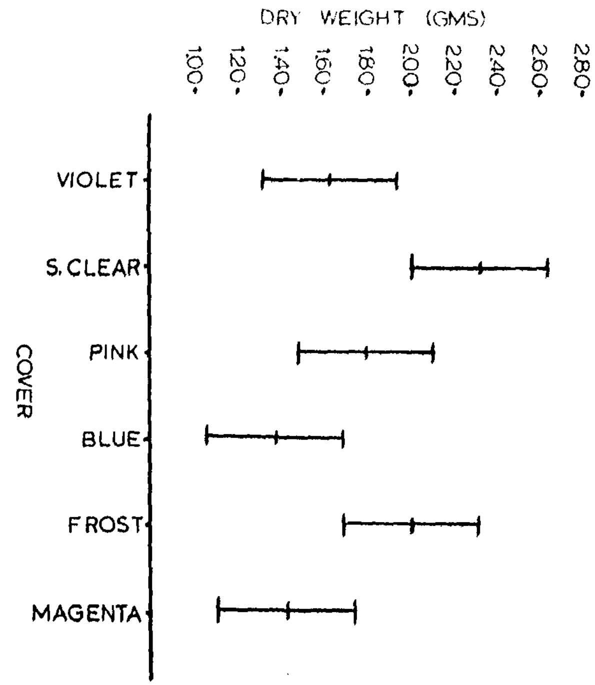
MARIGOLD FLOWER DEVELOPMENT						
COVER	TOTAL HT (cm)	DAYS TO FLOWER	TOTAL BREAKS	TOTAL FLOWERS	FRESH WT (gms)	DRY WT (gms)
VIOLET	10.66	44.00	2.30	1.32	3.18	0.355
S. CLEAR	10.55	39.94	2.36	1.87	4.22	0.477
PINK	10.41	41.43	2.00	1.48	2.78	0.313
BLUE	11.77	48.01	1.60	1.05	2.72	0.320
FROST	10.02	43.39	1.62	1.58	3.27	0.408
MAGENTA	11.03	44.36	1.01	1.21	2.17	0.244
Q = HSD[a]	0.579	2.076	0.638	0.344	0.556	0.088

[a] Tukey's honestly significant difference

Figure 23. Confidence intervals (95 percent) of mean dry weight production of Fireball II tomato plants harvested every three weeks after planting.

Figure 24. Confidence intervals (95 percent) showing the number of days required for flowering French marigolds grown under six cover treatments.


DAYS TO FLOWER
40.0
42.0
44.0
46.0
48.0
50.0
COVER
VIOLET
S. CLEAR
PINK
BLUE
FROST
MAGENTA


DRY WEIGHT (GMS)
1.00
1.20
1.40
1.60
1.80
2.00
2.20
2.40
2.60
2.80
COVER
VIOLET
S. CLEAR
PINK
BLUE
FROST
MAGENTA

Total breaks The total breaks present on each plant were an indication of flowering potential. The plants grown in the super clear, violet and pink treatments had significantly more breaks (Table 9) than those in all other treatments but showed no significant differences between each other.

Total flowers The super clear treatment produced the most flowers, but not significantly more than the frost or pink treatments.

Fresh and dry weights The fresh weights of plants harvested from the super clear treatment were significantly greater than those from any other treatment (Table 9). The plants having the greatest dry weight were also from the super clear treatment and the weights were significantly greater than those in all other treatments except the frost.

Development of Pinto beans

Development The data in Table 10 indicates that plants in the magenta and pink treatments both had significantly more development at the end of each 14 day growing period than in any treatment, but did not significantly differ between each other. There was no significant differences in development between the other treatments.

Total height The plants harvested in the magenta treatment were consistently and significantly taller when compared with all other treatments (Table 10). It should also be

Table 10. The mean growth rate and development responses of Pinto beans grown under six FRP panel covers.

BEAN GROWTH

COVER	DEVELOPMENT[b]	TOTAL HT (cm)	INTERNODES (cm)			WEIGHT (gms)		FIRST LEAF WIDTH (cm)
			FIRST	SECOND	THIRD	FRESH	DRY	
VIOLET	4.75	8.80	3.52	0.87	0.13	2.28	0.23	5.96
S. CLEAR	4.92	8.14	3.21	1.03	0.22	2.61	0.27	6.14
PINK	5.44	8.50	3.55	1.22	0.25	2.51	0.26	6.31
BLUE	4.83	9.12	4.21	1.20	0.25	2.45	0.24	6.25
FROST	4.82	7.45	3.02	0.88	0.22	2.45	0.25	6.04
MAGENTA	5.47	11.68	4.76	2.36	0.50	2.67	0.26	6.87
Q = H S D[a]	0.464	1.73	0.411	0.385	0.117	0.301	0.032	0.384

[a] Tukey's honestly significant difference

[b] Defined values,- see materials and methods

noted that the first, second and third internodes making up the total height of plants grown in the magenta treatment were significantly longer than those in all other treatments.

Fresh and dry weights   Fresh weight of plants grown in the magenta treatment was only significant when compared to growth under the violet treatment. There were no significant differences between the remaining treatments.

Dry weights of plants harvested in the super clear treatment was the greatest, but significant only over dry weight production in the violet compartment. No significant differences occurred between other combinations of treatments (Table 10).

Light Transmission

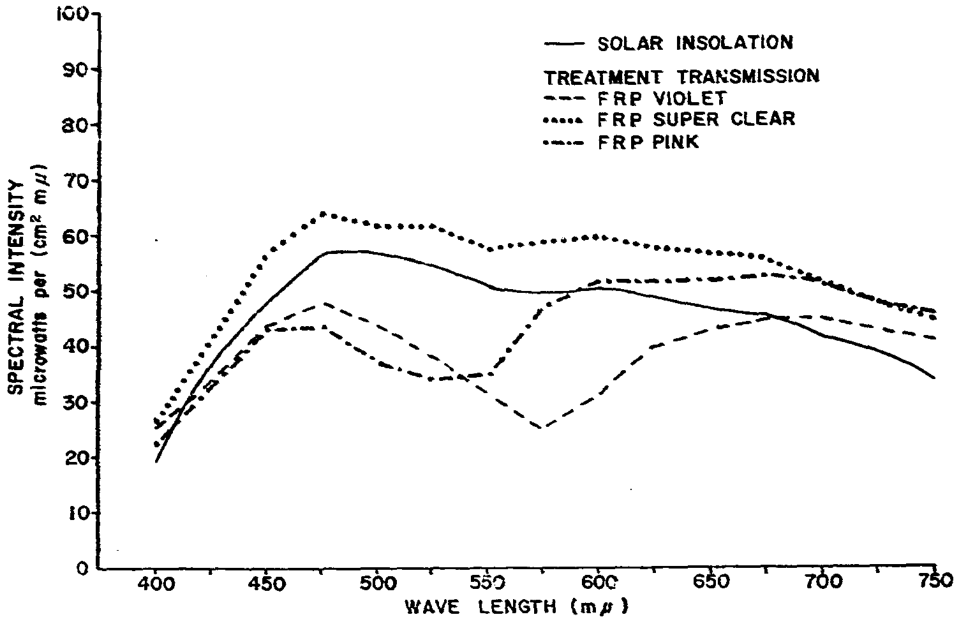
The transmission characteristics of each colored fiberglass reinforced plastic cover provided definite differences in available light and heat that contributed to the varied plant responses.

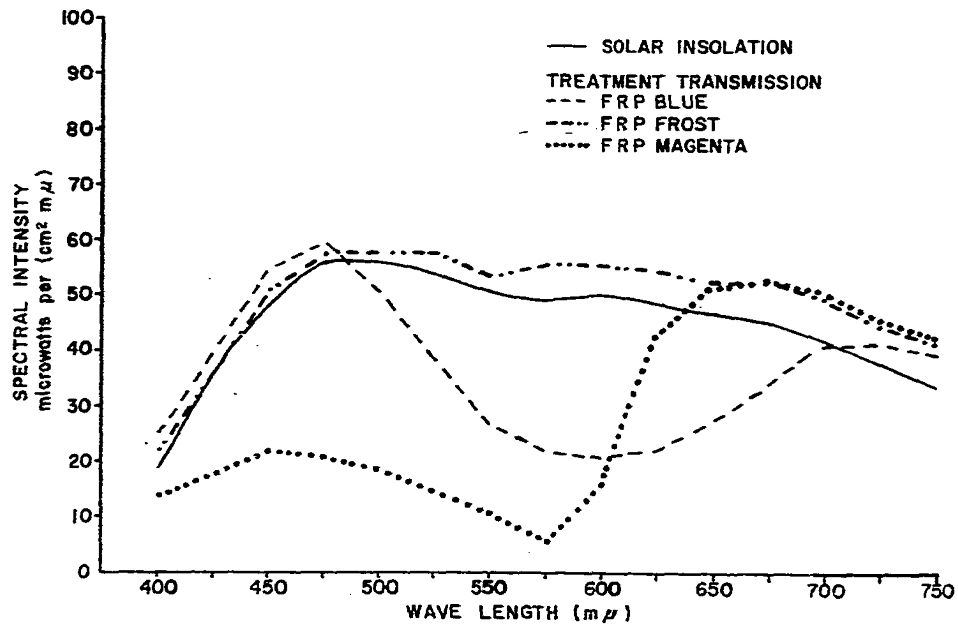
Spectral transmission characteristics

Figures 25 and 26 show the mean spectral transmission curves from 400 to 750 mμ for five random observations made on cloudless days between November 20, 1968 and January 9, 1969 inside each compartment. Figures showing the complete spectrum from 400 mμ to 1550 mμ are shown in Appendix A.

Figure 25. Mean spectral curves of unobscured light received under compartment coverings of FRP violet, super clear and pink between November 20, 1968 and January 9, 1969.

Figure 26. Mean spectral curves of unobscured light received under compartment coverings of FRP blue, frost and magenta between November 20, 1968 and January 9, 1969.


SOLAR INSOLATION
TREATMENT TRANSMISSION
FRP VIOLET
FRP SUPER CLEAR
FRP PINK
SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)


SOLAR INSOLATION
TREATMENT TRANSMISSION
FRP BLUE
FRP FROST
FRP MAGENTA
SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)

Figures 27 and 28 show the spectral distribution of wave lengths received in each compartment on January 12, 1969, a day with total overcast.

Light ratios   Table 11 shows the mean spectral intensities and significant differences between blue, green, red and far red bands of wave lengths that were transmitted by the treatment covers. Figure 29 graphically shows the spectral relationship of wavelengths in the same bands.

Heat transmission

Data from random four hours observations taken at midday between November 27, 1968 and Janaury 16, 1969 indicate that the radiant energy transmitted by each cover was significantly higher in the super clear treatment than any other treatment. It should be noted that the mean outside radiation was lower than the mean energy obtained under the super clear and frost treatments (Table 12).

Surface temperatures

Foliage   The foliage surface temperatures of tomato plants grown in the magenta and violet treatments were significantly lower than the leaf temperatures in any other treatment. There were no significant differences between other treatments (Table 12).

Black surface   The surface temperatures of black construction paper did not differ significantly between the pink and magenta treatments but they were significantly lower

Table 11. Mean intensities of wave length bands received under six FRP panel covers.

COVER	WAVE LENGTH INTENSITY microwatts per (cm^2 $m\mu$) BLUE 425-475$m\mu$	GREEN 525-550$m\mu$	RED 625-675$m\mu$	FAR RED 700-750$m\mu$
VIOLET	41.84	34.94	42.63	43.39
S. CLEAR	53.53	59.87	56.46	48.58
PINK	39.69	34.44	51.96	49.17
BLUE	51.09	33.29	27.44	41.69
FROST	47.84	56.24	53.03	46.39
MAGENTA	20.30	12.91	48.97	47.63
INCOMING INSOLATION	47.05	53.12	47.14	39.72
Q = HSD[a]	3.77	5.79	5.16	2.71

[a] Tukey's honestly significant difference

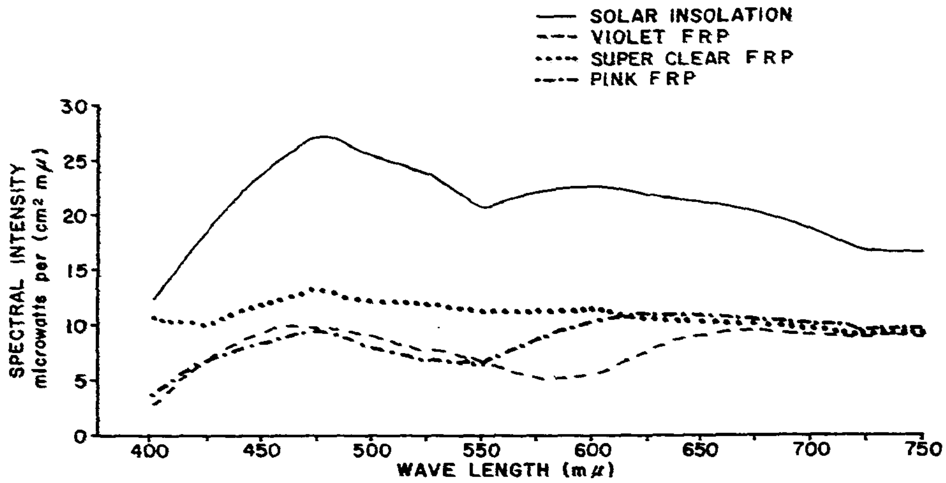
than in any other treatment (Table 12). The black surface temperatures in the super clear and frost were not significantly different but the black surface in the super clear treatment was warmer than all other treatments.

White surface The white surface temperatures were significantly cooler in the violet treatment and warmest in the super clear treatment, but not significantly warmer than those in the pink or frost treatments (Table 12).

A graphic representation of temperatures occurring on the surfaces of black and white paper and plant foliage under each treatment cover is shown in Figure 30.

Figure 27. Spectral distribution of light transmitted by violet, super clear and pink FRP panels on January 12, 1969, a day of total overcast.

Figure 28. Spectral distribution of light transmitted by blue, frost and magenta FRP panels on January 12, 1969, a day of total overcast.


SOLAR INSOLATION
VIOLET FRP
SUPER CLEAR FRP
PINK FRP
SPECTRAL INTENSITY microwatts per (cm² mμ)
WAVE LENGTH (mμ)

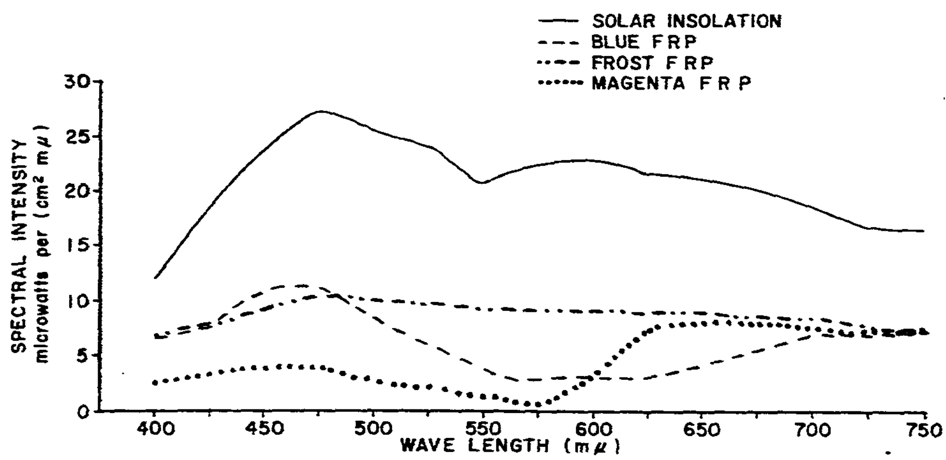
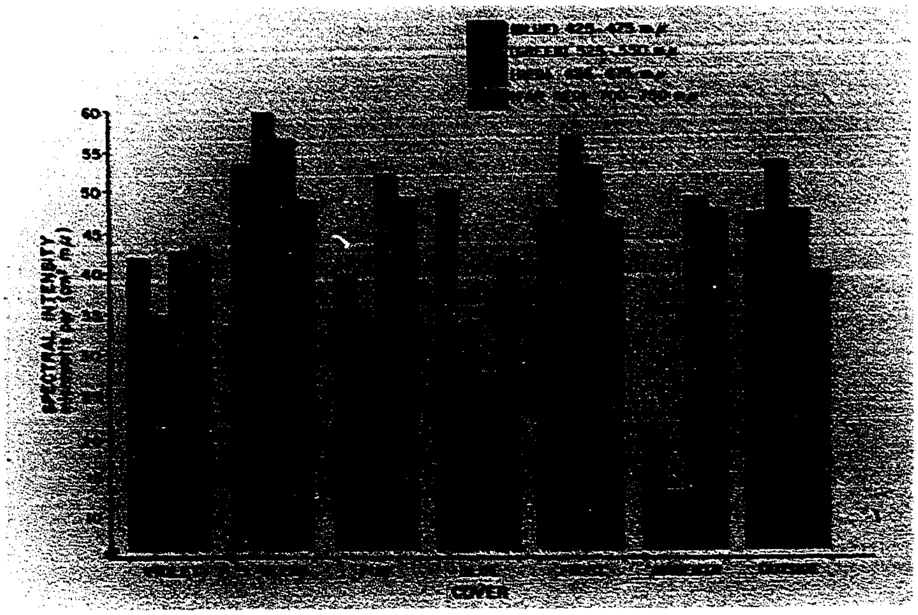
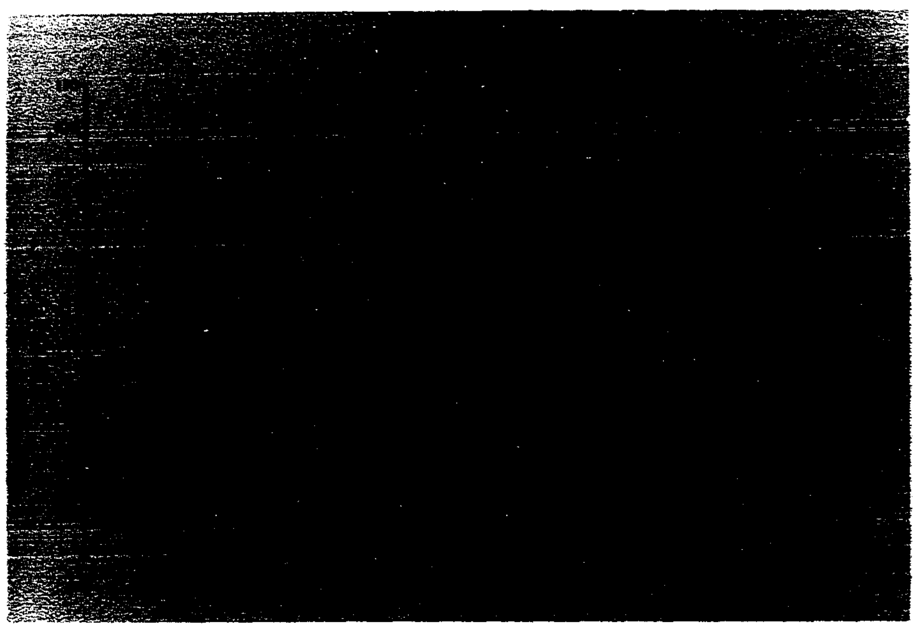

SOLAR INSOLATION
BLUE FRP
FROST FRP
MAGENTA FRP
SPECTRAL INTENSITY microwatts per (cm² mμ)
WAVE LENGTH (mμ)

Figure 29. Mean intensities of wave length bands of blue, green, red, and far red transmitted by six FRP coverings on 5 unobscured days between November 20, 1968 and January 9, 1969.

Figure 30. Mean surface temperatures of tomato foliage and black and white paper occurring in six compartments with various FRP coverings.


60
55
50
45
40
SPECTRAL INTENSITY



DISCUSSION

Plant Responses

The plant responses varied throughout the investigation and did not agree specifically with the results of previous researchers working with light quality.

Pfeiffer (49) in studying the effects of wave length on soybean found that the least differentiation occurred under blue light. This investigation revealed that Pinto bean plants in the blue treatment were as tall as those grown in all treatments except magenta and had greater development of branch primordia. The bean plants had lower fresh and dry weight under blue but not significantly lower than those grown in the violet or frost treatments. The greatest positive reaction to colored light by the bean plants occurred in the magenta treatment. The plants were equally as well developed as those in the pink treatment and were the tallest, having the longest internodes. The fresh and dry weights of beans grown in the magenta treatment were comparable to all treatments except violet and had significantly wider leaves. The excessive elongation of the bean in the magenta treatment is attributed to the decreased light intensity caused by the density of the cover, not necessarily the spectral transmission characteristics.

Popp (52) noted that anthesis of most plants involved in his experiments was delayed or stopped where no blue or violet was present. Hasselkus and Beck (28) found anthesis of *Pelargonium hortorum* was delayed in full spectrum light, when the intensity was decreased due to plant location. Buckholder (7) found that poor growth and decreased fresh and dry weights of several plant species occurred when the blue end of the spectrum below 529 mμ was excluded. This investigation indicates that the delay in the flowering of the marigold was highly significant under the blue treatment and fastest flowering occurred in the super clear and pink compartments. The development of bud clusters in both tomato evaluations also indicated poorer growth in blue light.

The frost treatment provided decreased light intensity when compared to the super clear treatment and no significant delay in the flowering of tomatoes was apparent, but flowering of marigolds in the frost treatment was significantly delayed.

The work by R. Van Der Veen (71) with tomato plants showed that blue light was an effective inhibitor of stem elongation. Similar results occurred in this investigation but plants grown under the frost treatment were shorter, though not significantly, than those grown in the blue treatment. The marigolds grown in the blue treatment were significantly taller than marigolds grown in all other treatments.

Dunn and Went (14, 72) indicated that a combination of blue and red fluorescent light, which resulted in decreased green in the spectrum, provided an excellent light for tomato growth. Similar results can be attributed to the spectral transmission characteristics created by the pink fiberglass reinforced plastic covering in this investigation. In most instances the plant growth response under the pink treatment was equal to the response of plants grown in the full spectrum under the super clear cover and better than those grown under the frost cover.

The response of plants grown in the violet treatment was somewhat ambiguous. Growth responses of the bean plants to the violet treatment were negative, although not necessarily significant, they had the lowest fresh and dry weight, development and smallest leaf width. The responses of marigolds and tomatoes grown under the violet cover seldom varied significantly from the responses of plants grown under the super clear, frost or pink treatments.

The lack of either a more positive or negative response in the violet treatment is probably due to temperature deviations. The violet chamber was on the end of the complex and was the only compartment with two walls exposed to the outside elements. During periods of cold weather the daytime temperatures would remain closer to 60°F than to 71°F, the cooling level. This no doubt was due to more radiating surface which resulted in approximately 35 percent less cooling time than was required by any other treatment.

Diffused light

On five random days during the investigation the following total cooling time requirements of each chamber were recorded in hours: violet, 2.63; super clear, 8.23; pink, 7.23; blue, 7.10; frost, 9.33 and magenta, 7.40. The super clear and frost required the most cooling. Table 12 shows that the super clear and frost compartments received significantly more heat energy than any treatment and under the super clear covering the mean energy was significantly greater than the energy received outside the compartments. It can also be noted that regions of the mean spectral transmission curves of insolation, Figures 25 and 26, was lower than the same regions of the curves created by the transmission characteristics of the various cover treatments. These intensity differences are attributed to the diffusing capabilities of fiberglass reinforced plastic panels which can be explained in the following manner. The total solar energy received by a flat target depends on the angle of the sun to the sensing element. The insolation readings during this investigation were taken with sensing elements of both the Sol-A-Meter and SR spectroradiometer horizontal to the earth's surface and the mean altitude of the sun was 30° above the horizon (Figure 31), thus the sensing

Table 12. The mean surface temperatures and BTU quantities obtained in six plant growth compartments with FRP panel covers.

	SURFACE TEMPERATURE F°			HEAT TRANSMISSION BTUs
COVER	FOLIAGE	BLACK	WHITE	
VIOLET	71.93	102.20	71.20	351.64
S. CLEAR	74.93	107.00	75.80	401.18
PINK	74.47	99.00	75.53	341.59
BLUE	74.07	102.93	74.27	305.08
FROST	75.40	106.20	75.07	389.94
MAGENTA	72.53	100.13	74.60	317.66
INCOMING INSOLATION		83.2[b]	50.46[b]	386.88
Q = HSD[a]	1.41	1.75	0.76	11.00

[a]Tukey's honestly significant difference

[b]Not considered statistically

elements were exposed to only a minimum amount of direct beam radiation. The formula, $A_{normal} = A_{horizontal} \times \text{Cos}\ \theta$ can be applied.

The cosine of 60°, is ½ and when applied to formula 1, the normal incidence reading is twice the horizontal reading.

1. $$R_{\substack{\text{normal}\\\text{incidence}}} = \frac{R_{\text{horizontal}}}{\text{Cos}_{\theta}}$$

2. $$R_{\substack{\text{normal}\\\text{incidence}}} = R_{\text{horizontal}} \times 2$$

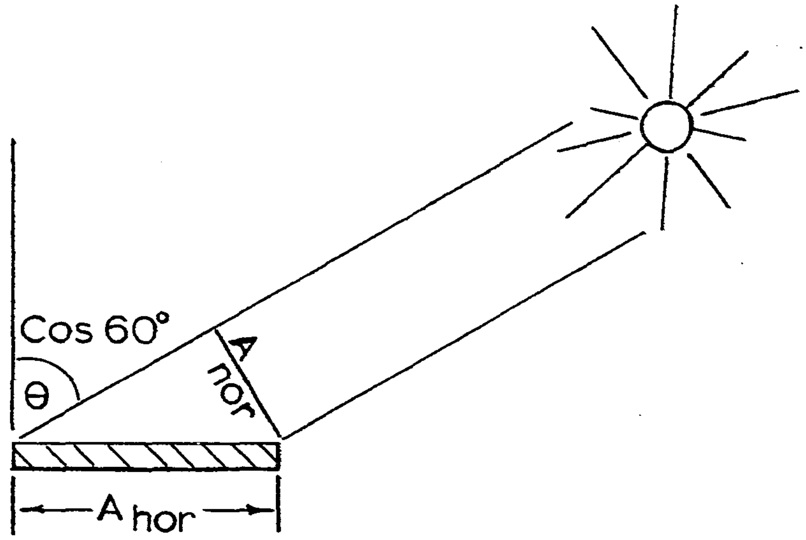
Figure 32 shows the mean spectral distribution curve of insolation, derived from formula 2, and compares it to the energy curve that was actually measured with the solar cell horizontal.

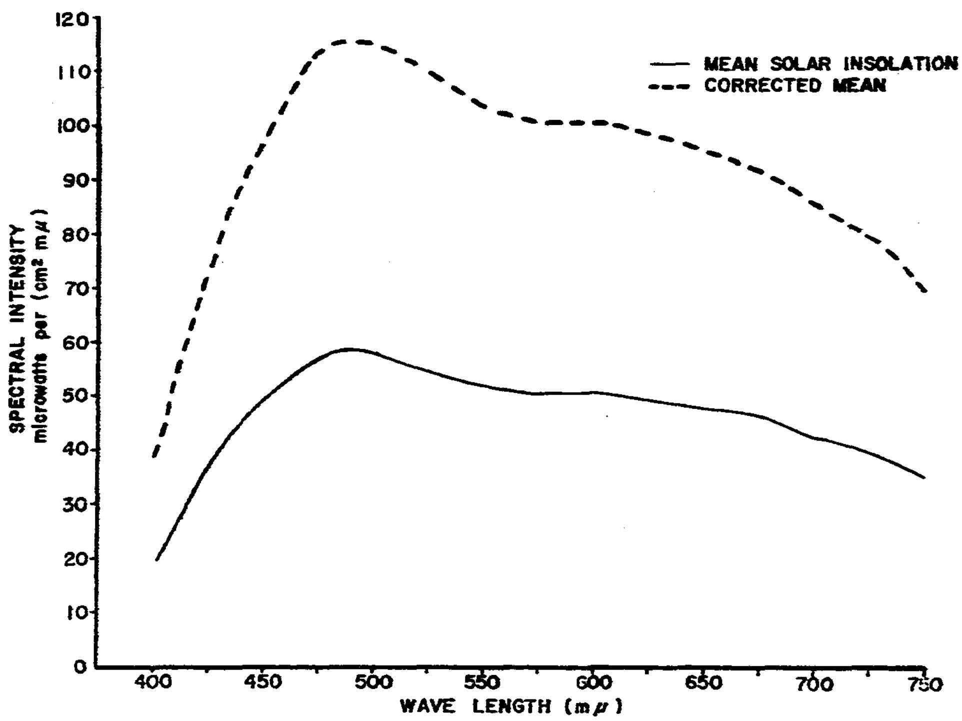
The sensing elements within each chamber received direct beam light plus all the diffused light created by the FRP cover. The small size of the compartments also created increased reflection and thus higher spectral and heat transmission readings.

The same principles can be applied to the absorption of light by plant foliage. The more the light is diffused the more energy there is available on a greater leaf area, potentially resulting in increased photosynthesis.

Figure 31. Graphic representation of target area receiving radiation when the sun is at an altitude of 30°.

Figure 32. Insolation curve corrected for the low angle of the sun to the sensing element.


Cos 60°
θ
A nor
A hor


MEAN SOLAR INSOLATION
CORRECTED MEAN
SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)
0
10
20
30
40
50
60
70
80
90
100
110
120
400
450
500
550
600
650
700
750

We can then surmise that the plant growth in the super clear and frost treatments was due mainly to the total energy available as a result of diffused and subsequently reflected light created by the design of the chamber and not the ratios of the various wave lengths.

Light energy

Table 13 shows the energy levels equivalent to the spectral intensities within each color band represented in Table 12. The total energy from incident radiation received in the super clear and frost compartments was higher than the insolation energy outside the chambers. Growth (dry weight) of tomato and marigold plants in each compartment was almost directly proportional to the total energy and the different energy levels had no effect on the dry weight production of beans. It is thus postulated, there was adequate energy for "good" plant growth under the pink cover and the incident radiation received at plant level was more than enough under the super clear and frost covers. It is also possible that the lowest energy received in any one compartment was more than adequate for "normal" growth of Pinto beans and the energy balance in each spectral band was not limiting.

Temperatures

The foliage temperatures evidently had little effect on plant growth if we consider that there were no significant

Table 13. Mean energy bands of blue, green, red and far red unobscured light randomly received at midday between November 20, 1968 and January 9, 1969 in six compartments covered with violet, super clear, pink, blue, frost and magenta FRP panels.

ENERGY RECEIVED[a] - ergs per sec per cm^2					
	BLUE (425-475 $m\mu$)	GREEN (525-550 $m\mu$)	RED (625-675 $m\mu$)	FAR RED (700-750 $m\mu$)	SUM OF BANDS
VIOLET	209.20	87.35	213.20	216.95	726.70
S. CLEAR	267.65	149.67	282.30	242.90	942.52
PINK	198.45	86.10	259.80	245.85	790.20
BLUE	255.45	83.22	137.20	208.45	684.32
FROST	239.20	140.60	265.15	231.95	876.90
MAGENTA	101.50	32.27	244.90	238.15	616.82
OUTSIDE	235.30	132.80	235.70	198.60	799.40

[a]All numbers x 10^2

foliage temperature differences between the super clear, frost, pink and blue treatments. The surfaces of tomato foliage grown in the violet and magenta were significantly cooler than foliage surfaces in the remaining treatments. The cooler foliage in the violet treatment correlates well with the lower white surface temperatures and decreased cooling requirements in the compartment.

Condensate that forms on the inside surfaces of plastic greenhouse coverings, often falls as droplets. During the course of this investigation the presence of condensate was noted on the inside surfaces of the super clear and frost coverings and its absence noted on the colored coverings. Inside surface temperatures of the panels were measured with the Barnes infrared thermometer and it was found that the super clear and frost were 4^{o} to $13^{o}F$ cooler than the colored covers.

The visible light passing through the colored FRP coverings is absorbed by pigment particles and increases the temperature of the surrounding plastic and glass media, thus evaporating the condensate. The colorless or frosted type FRP panels do not have pigments which absorb light and the plastic remains cool.

SUMMARY

Six temperature controlled chambers were covered with fiberglass reinforced polyester plastic panels. Four chambers were covered with selected colored panels, and the remaining two with panels of greenhouse grade super clear and frost. The wave lengths transmitted by super clear and frost were comparable in quality and quantity to the spectrum of insolation. The four colored covers, blue, magenta, pink and violet respectively, modified the transmitted light into 1. a high peak in blue, 2. a high peak in red, 3. medium peak of blue and high red, and 4. equal peaks of red and blue.

Responses of seedling tomatoes, French marigolds and Pinto beans were:

1. Bud development of tomato plants grown in the super clear and pink was significantly faster than in the other treatments. Plants from the blue and magenta treatments were slowest.
2. Fresh and dry weights of tomato plants grown in the super clear, pink and frost treatments were consistently higher. Weights in the blue and magenta treatments were lowest.
3. The development, total height, internode lengths, fresh and dry weights and leaf widths of bean plants grown in the magenta treatment were consistently

higher throughout the investigation. The bean plants grown in the pink and super clear treatments did not differ significantly in development and fresh and dry weights when compared to those grown in the magenta compartment. Bean plants in the violet and blue treatments produced the least desirable growth.

4. French marigolds flowered the fastest in the super clear treatment but did not differ significantly from the rate of flowering in the pink treatment. The fresh weight in the super clear treatment was highly significant. There were no significant differences between the fresh weight production in the frost, pink and violet treatments. The super clear, frost and violet treatments produced the greatest dry matter, and the blue cover treatment yielded the tallest marigolds with high significance.

In general, plants grown in the blue and magenta treatments responded least favorably to the spectral environment.

The spectral and heat transmission characteristics of the various coverings were evaluated as follows:

1. Surface temperatures of tomato foliage in the violet and magenta treatments were significantly lower than surface temperatures of tomato foliage in all other compartments.

2. The surface temperatures of black paper in the pink and magenta treatments were significantly lower than the other treatments and super clear and frost the highest.

   The coolest and most significant white surface temperature occurred in the violet treatment. The warmest white surface temperatures occurred in the super clear, frost and pink treatments.

3. The direct and diffused radiation received in the super clear compartment was significantly greater than in any other treatment or incoming radiation. The diffusion characteristics of FRP created more usable light for plant growth.

4. Heat absorption by the color pigments in the colored FRP increased the temperature of the panel and condensate on the underside was eliminated during daylight hours. Condensate remained on the clear and frost panels.

5. Decreased energy in the green portion of the spectrum due to the pink cover had little adverse effect on the growth of plants.

GENERAL DISCUSSION

From the beginning of time, all agronomic and ornamental crops have generally been bred, selected and grown in environments with unmodified solar energy. Popp (52) and Pfeiffer (49) showed that the growth responses of several plant species were better under insolation containing a complete spectrum than under light with various wave lengths deleted. This investigation showed that the green portion of the light spectrum can be decreased by violet and pink covers and plant growth comparable to growth under the non-modified spectrum obtained. The three plant species responded differently to the modified light treatment indicating growth of specific plants may be regulated, to a degree, by varying the ratio of incoming blue, green, red and far red light. Much more research is needed to evaluate, with time, the effects of modified solar energy as a light source for specific plant species.

Differences in light energy under the various covers were apparently major controlling factors in plant response. Blackman (4) and Burkholder (8) found that plant growth accelerated as intensity increased until light saturation was reached. All covers evaluated in part I, except aged frost FRP, evidently provided plants with adequate light energy and perhaps reached light saturation. Plant responses in part II may have been due to total energy available and not a direct function of wave length intensity.

The comparable growth obtained under the super clear, pink and frost FRP covers indicated the energy received under the pink cover may have saturated the plants and that received under super clear and frost may have been in access.

Several FRP panel manufacturers market super clear panels which differ in translucency. Continued research is necessary to evaluate growth responses to light transmitted by these panels in geographical locations involving altitude, latitude and available solar energy.

Plant temperatures, within environments utilizing solar radiation may be partially controlled by the translucency or color of the covering. Even though data were not taken in this investigation, it is likely that covers may have affected also the transpiration rates of the plants and the water absorbing power of the plant atmosphere. Part I of this investigation showed translucency of the cover affected surface temperatures of foliage and flower petals. Under a highly translucent (transparent) cover decreased relative humidity, increased foliage temperatures and transpiration, limited moisture supply in root zone and restricted plant growth may result. Interactions of transpiration and temperature under greenhouse coverings need to be studied.

Aside from the direct effects of modifying the light spectrum and decreasing plant temperatures, pink tinted greenhouse coverings may result in easier control of cooling even though there was no indication that less infrared energy was transmitted by the pink and magenta covers. The decreased temperatures under the pink cover can possibly be attributed to more IR reflected on the surface plus the decreased energy transmitted in the green portion of the spectrum.

The light diffusing capabilities of FRP panels may provide more available energy for photosynthesis than glass. Additional research is needed to study photosynthetic responses to diffused light.

The incorporation of glass fibers into greenhouse grade glass could provide diffusing characteristics superior to those obtained by sandblasting and equal to the diffusing characteristics of FRP panels. Tinting of glass in pink hues for greenhouse applications should also be considered.

SUMMARY

Transmissivity characteristics of glass and fiberglass reinforced plastic panels (FRP) were evaluated with pyranometers, a spectroradiometer, an infrared thermometer and by plant responses.

In the first part of the investigation the transmissivity characteristics of greenhouse glass and FRP panels of frost, clear and super clear were determined with red and white flowered varieties of carnation (*Dianthus caryophyllus*). Growth responses differed with varieties. Plants under the super clear produced the most red and white flowers and plants under frost, the least. Plants grown under clear produced the lightest weight red flowers. The shortest stems on plants of both flower colors were produced under glass.

Surface temperatures of black and white paper, red flowers and foliage were significantly higher under glass and lower under frost. Small differences were observed in the proportion of blue, green, red and far red light transmitted by the coverings. The percentage energy transmitted as heat and light decreased progressively under glass, super clear, clear and frost.

The second part of the investigation involved the construction of chambers covered with fiberglass reinforced panels of super clear, frost and selected colors of blue, magenta, pink and violet.

French marigolds (*Tagetes patula*), Pinto bean (*Phaseolus vulgaris*) and tomato (*Lycopersicon esculentum*) responded differently when grown under sunlight modified by the tinted panels. Marigolds produced the greatest dry matter under super clear, frost and violet, and the tallest plants under blue. Pinto beans grew more rapidly under pink and magenta. Differences in dry weight were not significant. Tomato plants produced more buds more rapidly and the fresh and dry weights were consistently higher under super clear, pink and frost than under blue and magenta.

The surface temperatures of tomato foliage were lowest under violet and magenta and highest under frost. Surface temperatures of black paper were lowest under pink and magenta and highest under super clear and frost.

The greatest total light energy was transmitted by super clear and frost and the least by magenta.

Condensate present during daylight hours on super clear and frost was not observed on the tinted panels.

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APPENDIX A. SPECTRAL TRANSMISSION CURVES

Part I transmission curves (400-1500 mμ)

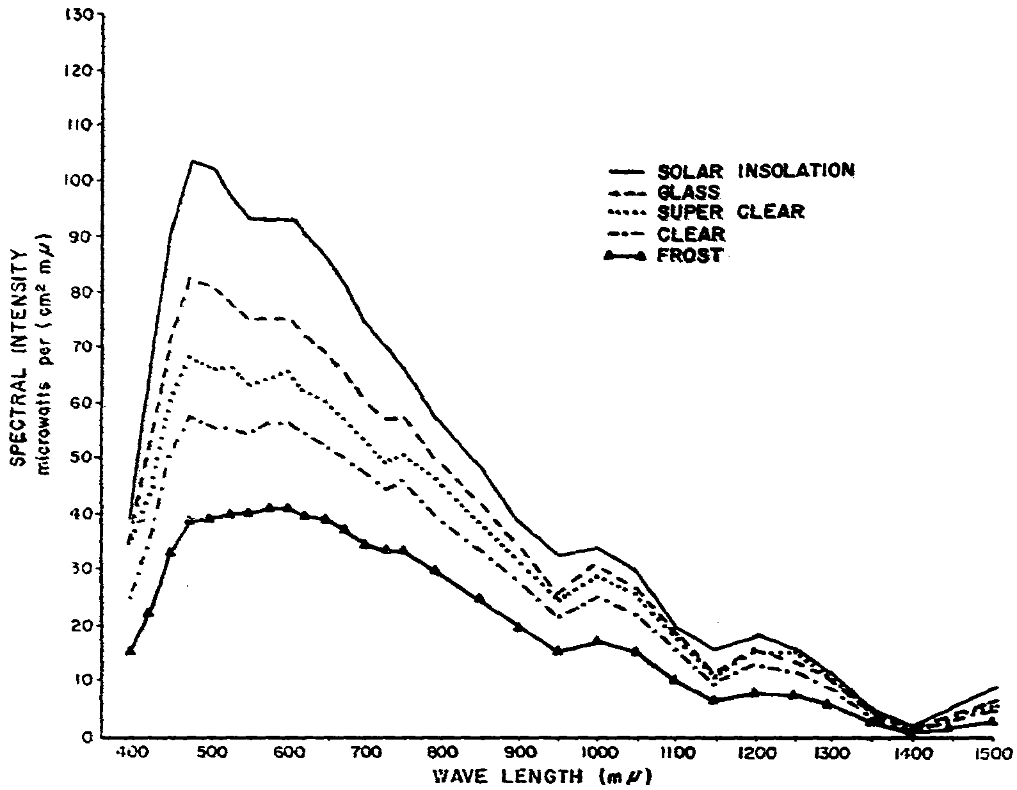
Figures 33 and 34 represent the spectral characteristics of light transmitted by greenhouse coverings of glass and FRP frost, clear and super clear panels between December 21, 1967 and June 22, 1968. The curves represent data taken at midday; mountain standard time, when the sky was cloudless and as far as could be visually determined, free of adverse atmospheric conditions including haze.

Part II transmission curves (400-1500 mμ)

The mean spectral characteristics of light received in chambers covered with greenhouse grades of FRP super clear and frost and tinted FRP panels of violet, pink, blue and magenta are shown in Figures 35 and 36. The spectral characteristics represent five random, unobscured observations made at midday between November 20, 1968 and January 9, 1969.

Figure 33. Mean spectral characteristics (400-1550 mμ) of light transmitted by four coverings between December 21, 1967 and June 22, 1968.

Figure 34. Percent of insolation (400-1550 mμ) transmitted by four coverings described in Figure 33.


SOLAR INSOLATION
GLASS
SUPER CLEAR
CLEAR
FROST
SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)

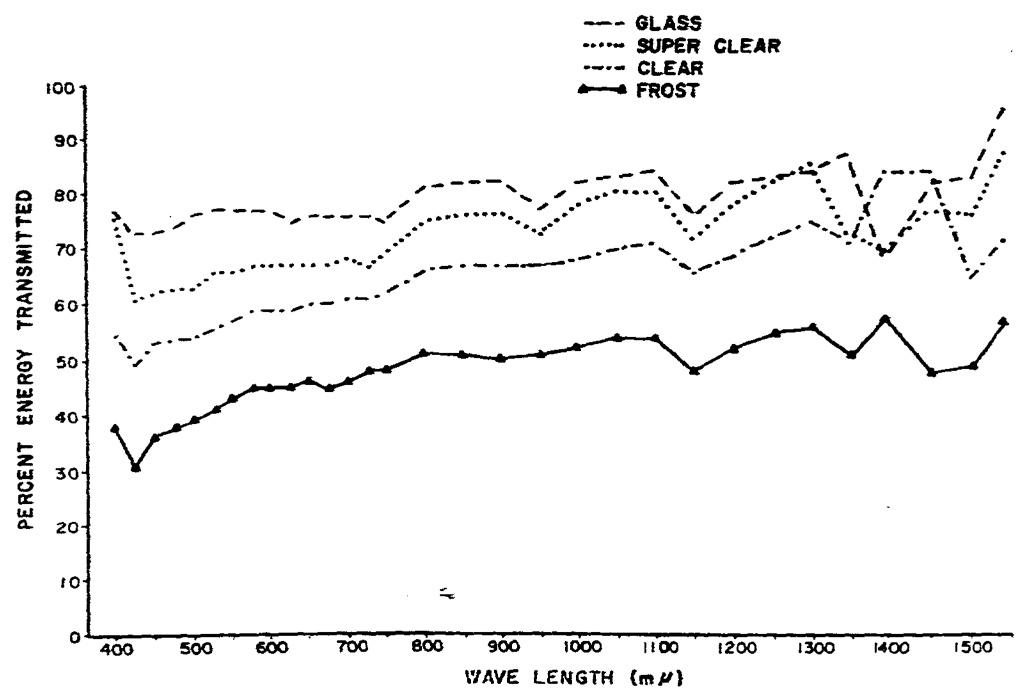
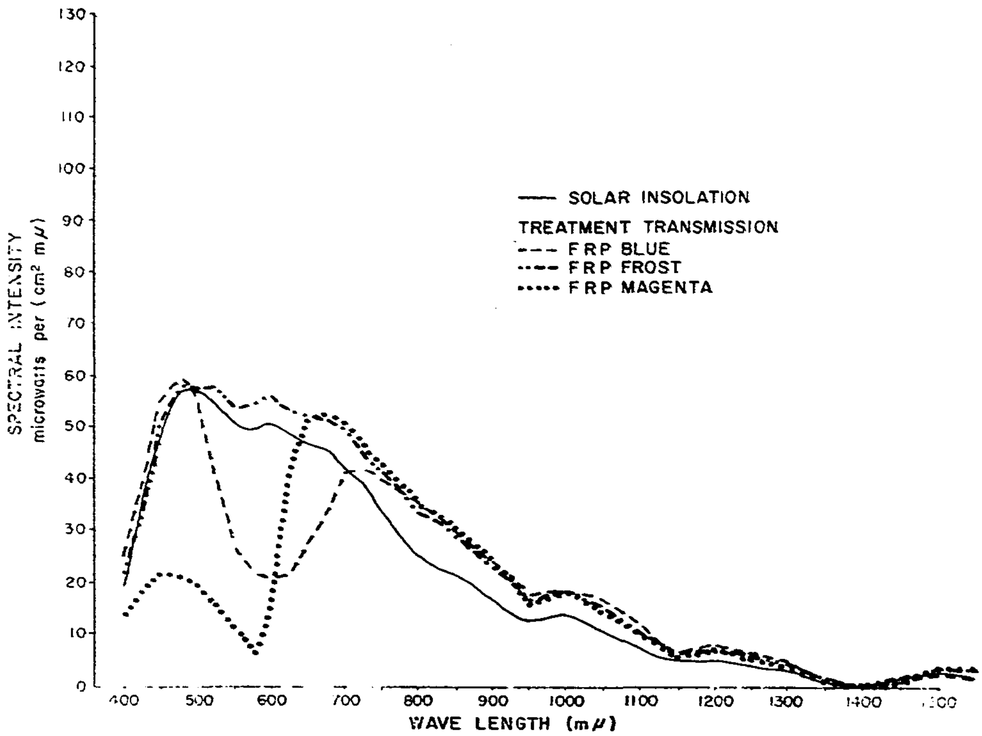
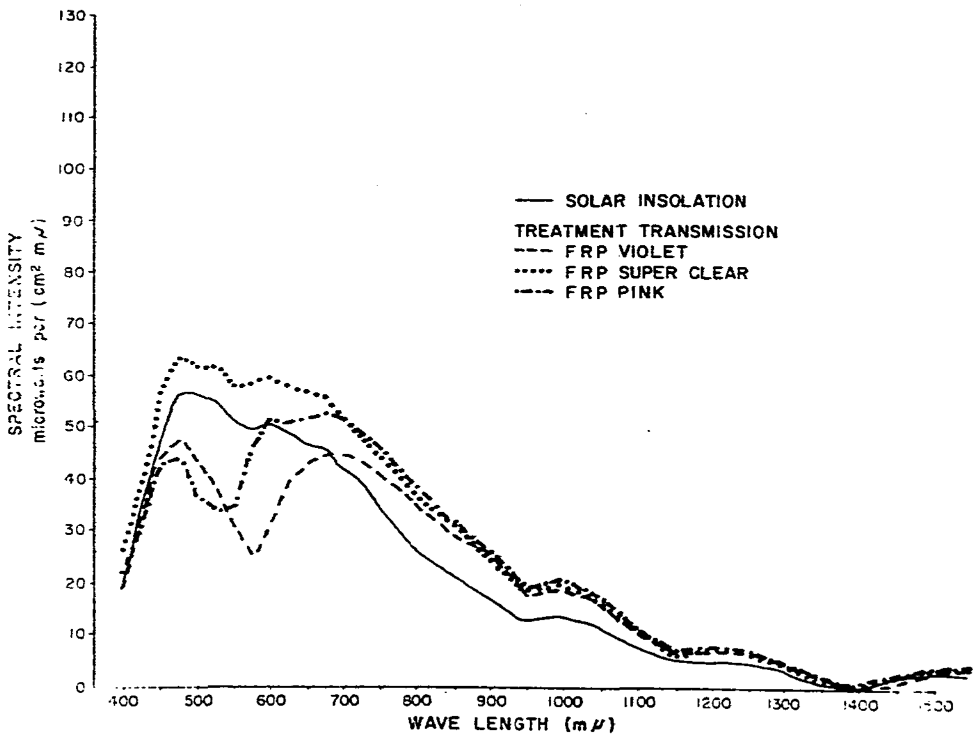

GLASS
SUPER CLEAR
CLEAR
FROST
PERCENT ENERGY TRANSMITTED
WAVE LENGTH (mμ)

Figure 35. Mean spectral energy received at plant height under colored panel of FRP blue, frost and magenta.

Figure 36. Mean spectral energy received at plant height under colored panel of FRP violet and pink and super clear.


SOLAR INSOLATION
TREATMENT TRANSMISSION
FRP BLUE
FRP FROST
FRP MAGENTA
SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)


SOLAR INSOLATION
TREATMENT TRANSMISSION
FRP VIOLET
FRP SUPER CLEAR
FRP PINK
WAVE LENGTH (mμ)

APPENDIX B. CHAMBER DEVELOPMENT AND EQUIPMENT

Coverings

Roscolene samples The following forty-four tinted Roscolene plastic samples were visually screened for transmission characteristics:

Rosco Nos.	Color Designation	Rosco Nos.	Color Designation
801	Frost	835	Medium Salmon Pink
802	Bastard Amber	837	Medium Magenta
804	No Color Straw	838	Dark Magenta
805	Light Straw	839	Rose Purple
806	Medium Lemon	841	Surprise Pink
807	Dark Lemon	842	Special Lavender
809	Straw	843	Medium Lavender
810	No Color Amber	846	Medium Purple
811	Flame	850	No Color Blue
813	Light Amber	851	Daylite Blue
815	Golden Amber	855	Azure Blue
817	Dark Amber	856	Light Blue
818	Orange	857	Medium Blue
819	Orange-Amber	858	Light Green Blue
821	Light Red	859	Green Blue (Moonlight)
823	Medium Red	861	Surprise Blue
825	No Color Pink	863	Medium Blue
826	Flesh Pink	866	Dark Urban Blue
828	Follies Pink	871	Light Green
830	Medium Pink	874	Medium Green
832	Rose Pink	877	Medium Blue Green
834	Salmon Pink	878	Yellow Green

The spectral transmission characteristics (400-1500 mμ) of the nineteen Roscolene samples chosen visually, were analyzed at midday on April 8, 1968, a cloudless day, and on April 9, 1968, during a period of total overcase (Figures 37, 38, 39, 40 and 41). The unobscured insolation curve represents

Figure 37. Spectral transmission curves of Rosco samples 802, 819, 825 and 826 on an unobscured and totally overcast day.

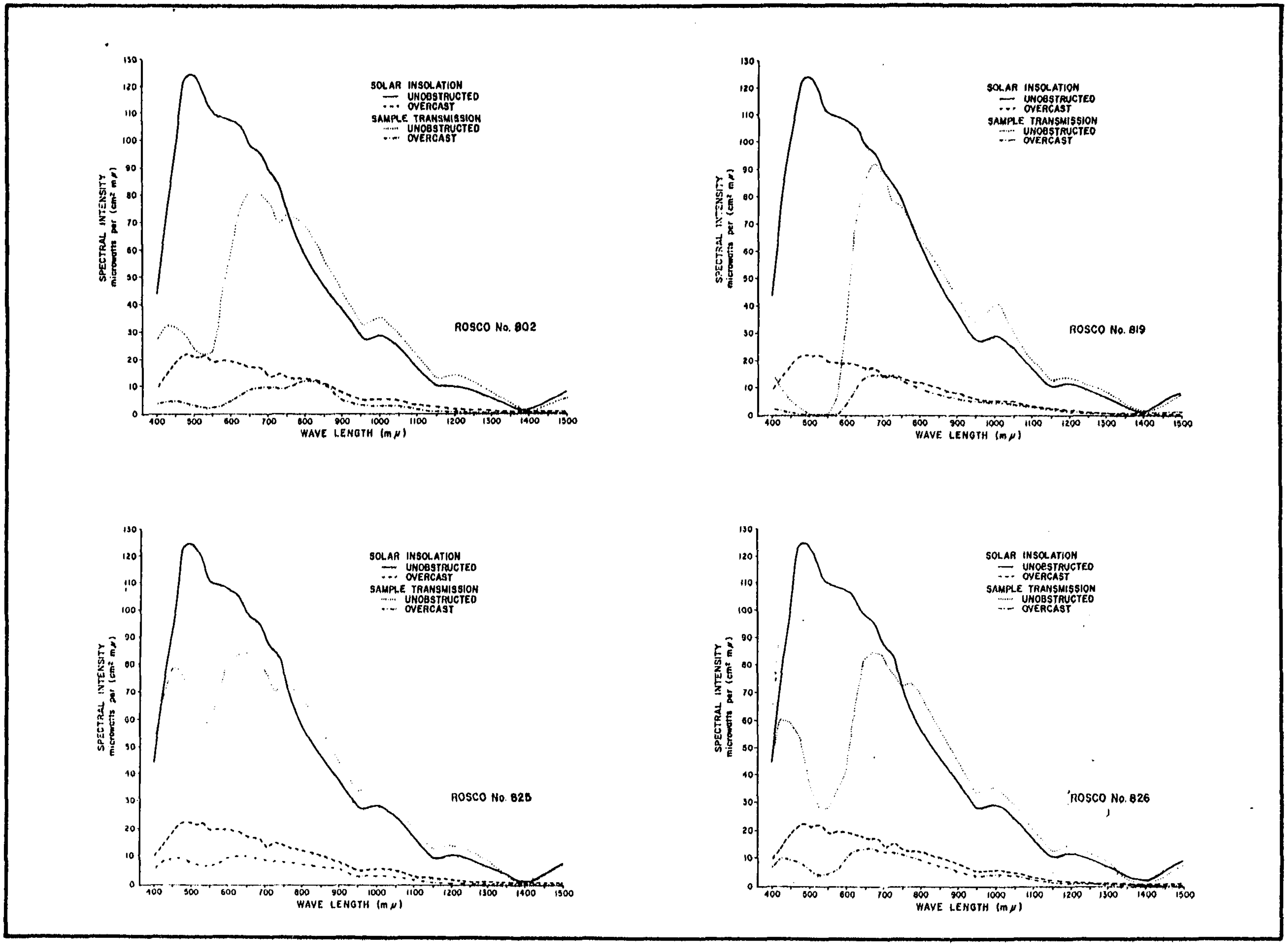

SOLAR INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)
ROSCO No. 802
ROSCO No. 819
ROSCO No. 825
ROSCO No. 826

Figure 38. Spectral transmission curves of Rosco samples 830, 832, 834 and 837 on an unobscured and totally overcast day.

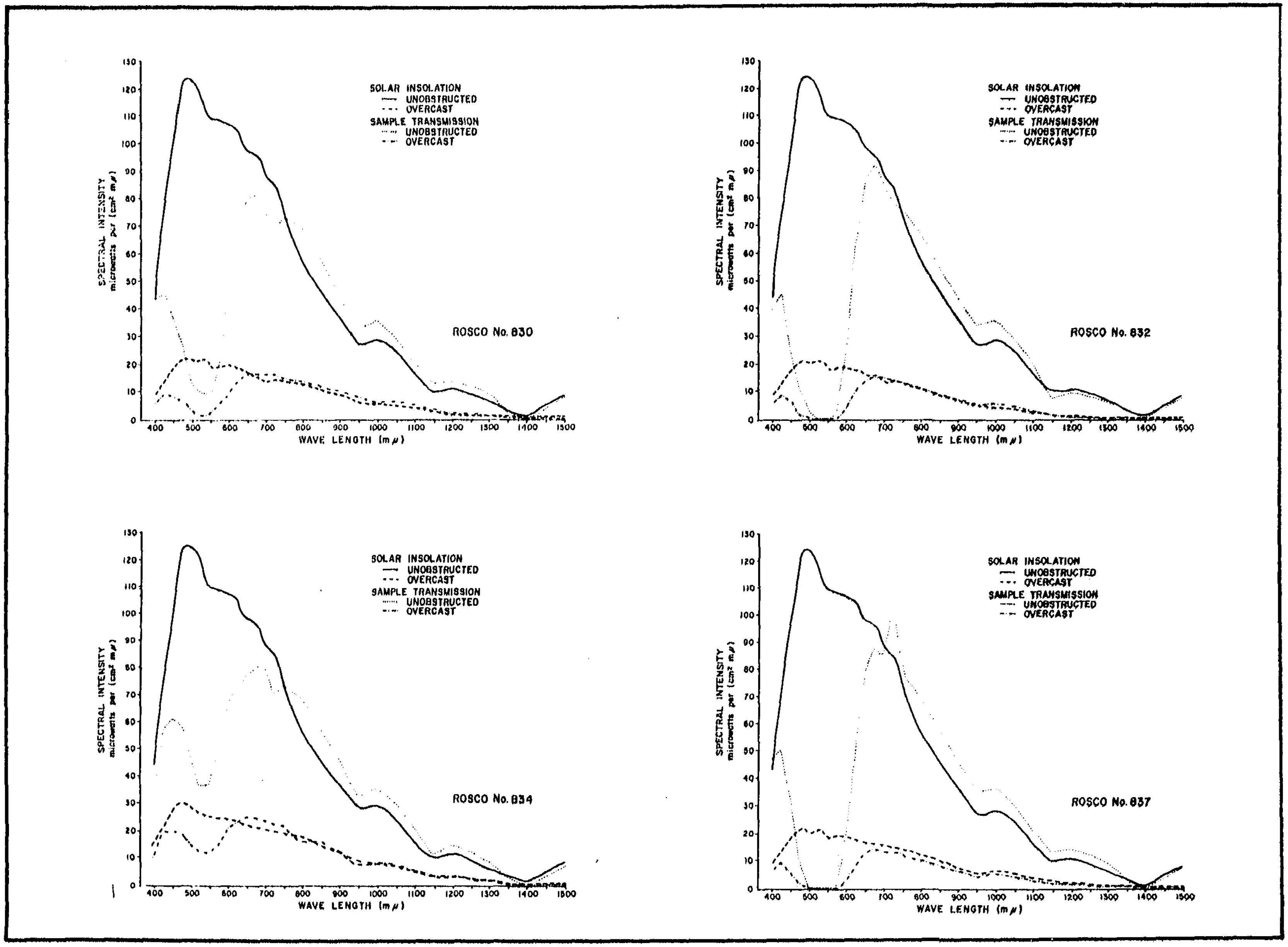
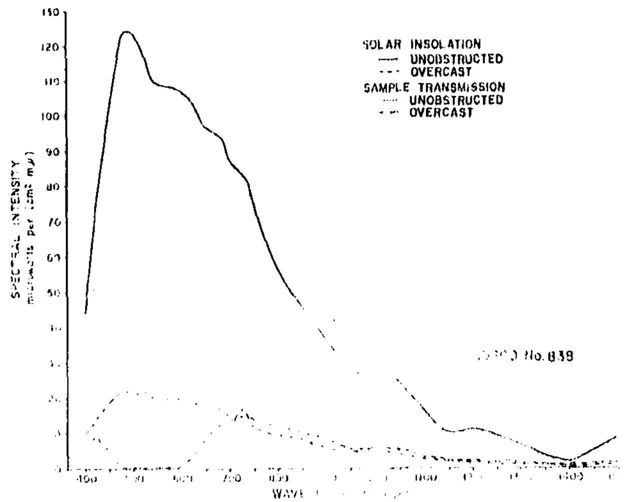
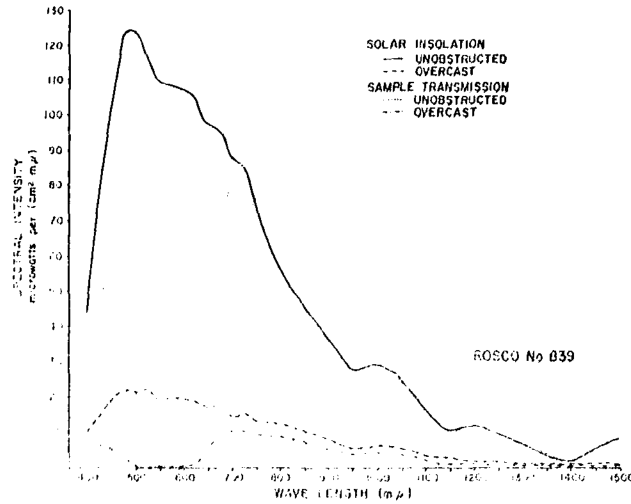
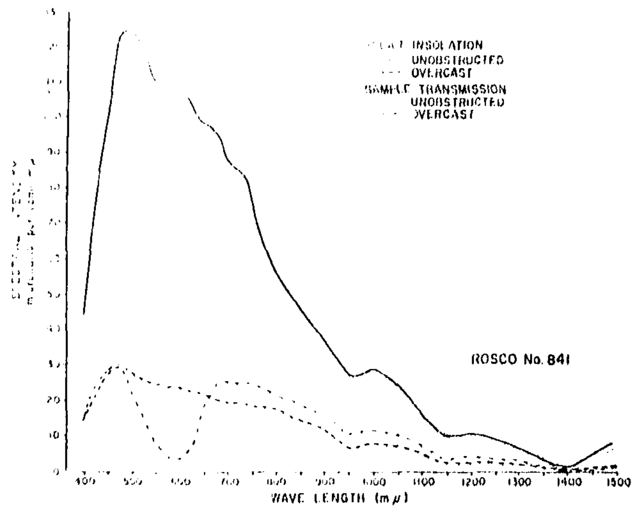

SOLAR INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)
ROSCO No. 830
ROSCO No. 832
ROSCO No. 834
ROSCO No. 837

Figure 39. Spectral transmission curves of Rosco samples 838, 839, 841 and 842 on an unobscured and totally overcast day.


SOLAR INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
No. 839


SOLAR INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
ROSCO No 839
WAVE LENGTH (mμ)


INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
ROSCO No. 841
WAVE LENGTH (mμ)

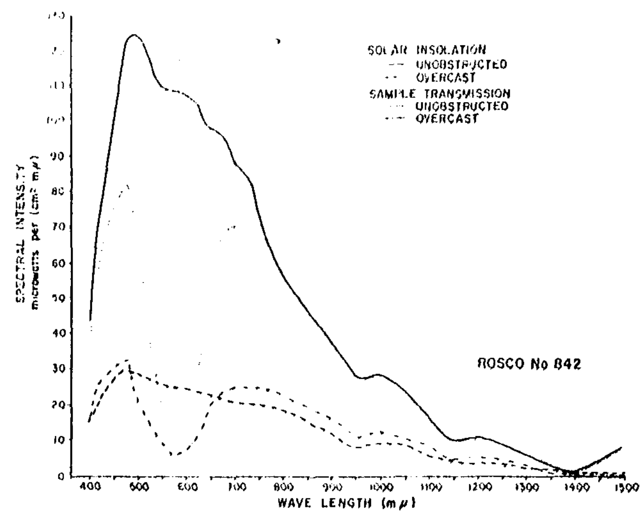
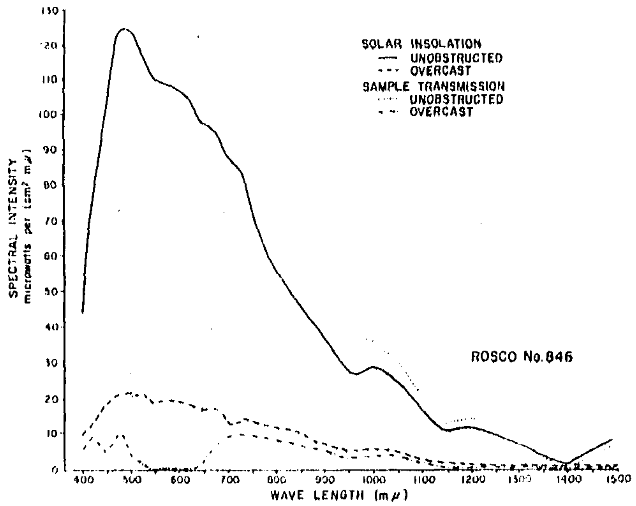
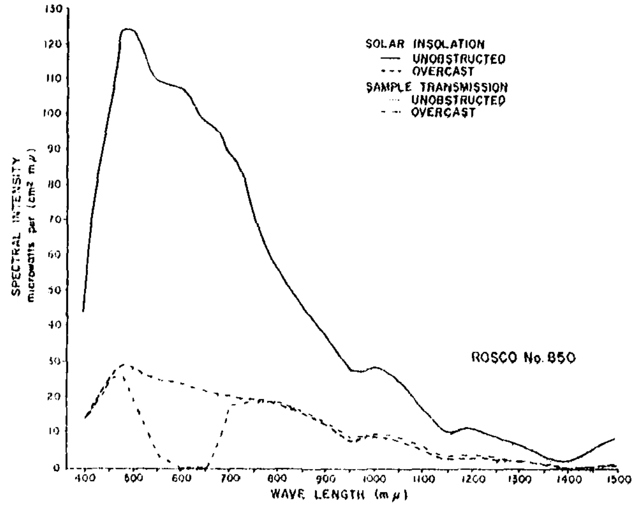
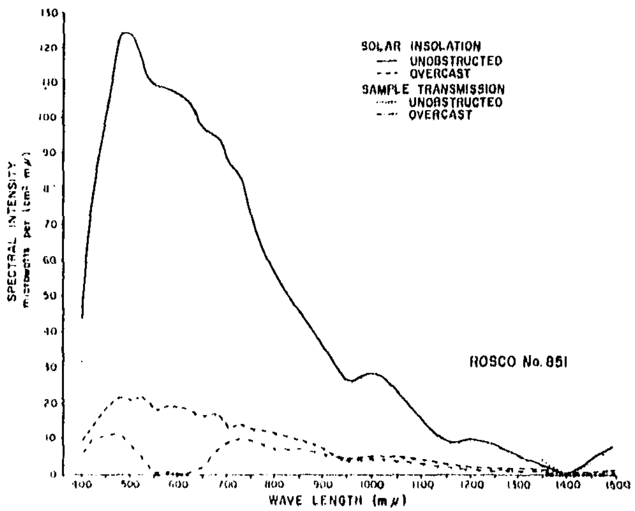

SOLAR INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
ROSCO No 842
SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)

Figure 40. Spectral transmission curves of Rosco samples 846, 850, 851 and 857 on an unobscured and totally overcast day.


SOLAR INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
SPECTRAL INTENSITY
microwatts per (cm² mμ)
ROSCO No. 846
WAVE LENGTH (mμ)


SOLAR INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
SPECTRAL INTENSITY
microwatts per (cm² mμ)
ROSCO No. 850
WAVE LENGTH (mμ)


SOLAR INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
SPECTRAL INTENSITY
microwatts per (cm² mμ)
ROSCO No. 851
WAVE LENGTH (mμ)

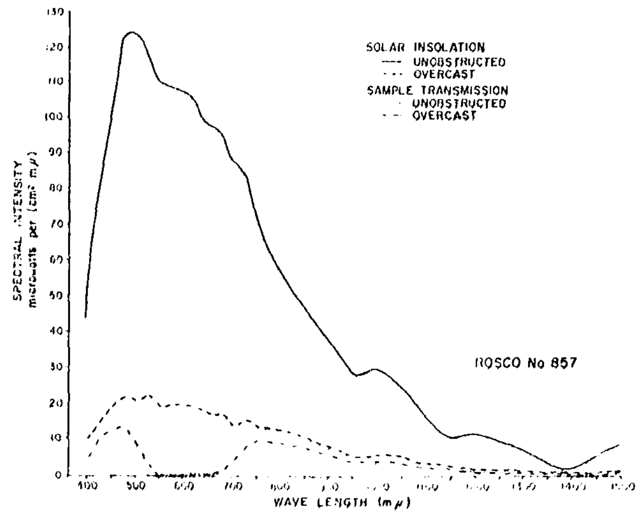
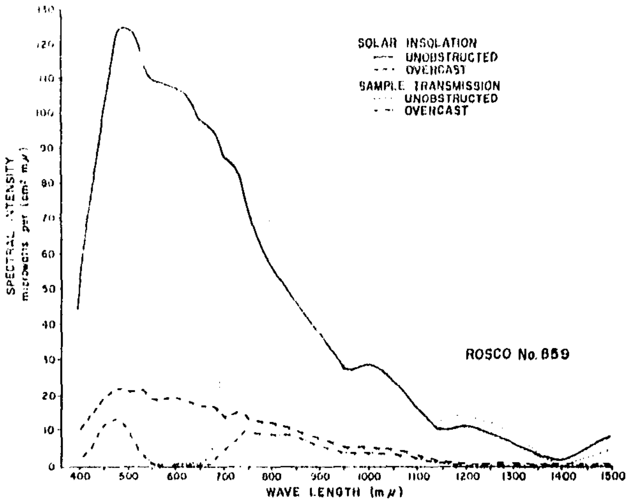
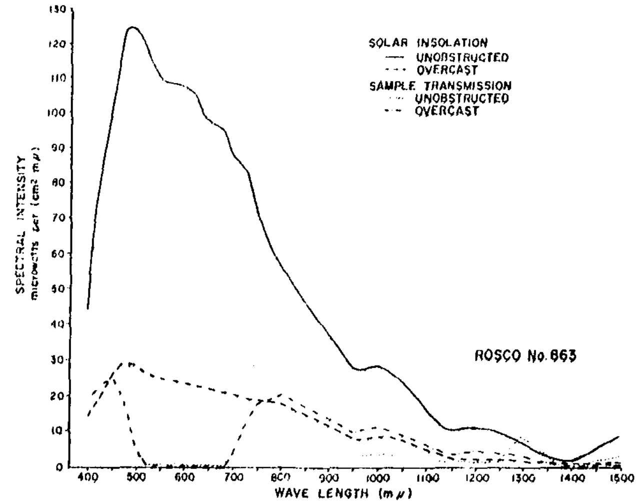
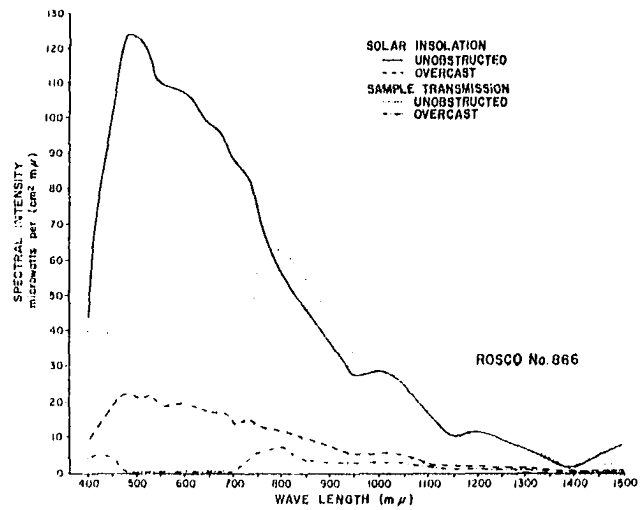

SOLAR INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
SPECTRAL INTENSITY
microwatts per (cm² mμ)
ROSCO No 857
WAVE LENGTH (mμ)

Figure 41. Spectral transmission curves of Rosco samples 859, 863 and 866 on an unobscured and totally overcast day.


SOLAR INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
SPECTRAL INTENSITY
microwatts per (cm² mμ)
ROSCO No. 859
WAVE LENGTH (mμ)


SOLAR INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
SPECTRAL INTENSITY
microwatts per (cm² mμ)
ROSCO No. 863
WAVE LENGTH (mμ)


SOLAR INSOLATION
UNOBSTRUCTED
OVERCAST
SAMPLE TRANSMISSION
UNOBSTRUCTED
OVERCAST
SPECTRAL INTENSITY
microwatts per (cm² mμ)
ROSCO No. 866
WAVE LENGTH (mμ)

the mean of several analyses and was often lower in intensity than the sample curve obtained with a single analysis.

Corporation samples The spectral transmission characteristics of the FRP laboratory samples, which were comparable in color to the four selected Roscolene filters, are shown in Figures 42, 43 and 44. The Rosco samples used as a color guide for the FRP samples were: no. 825 - pink FRP, no. 832 - magenta FRP, no. 842 - violet FRP and no. 851 - blue FRP. Spectral analyses were accomplished at midday on June 27, 1968, using unobscured insolation as the light source.

Equipment

Control equipment The following equipment was used to control the environment in the Spectral Transmission Laboratory chambers:

a[1,2] exhaust fan - 6 in., 550 CFM, 1/40 HP, Stock no. 2C634

b[1,3] temperature controls - miniature thermostats pre-set at factory, 3.0 in. long x 1/8 in. dia., $\pm .1^{\circ}C$ sensitivity and accuracy. Cat. no. TM-803

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[1]Corresponds to legend in Figure 18.

[2]W. W. Grainger Inc., Chicago, Illinois.

[3]Philadelphia Scientific Glass Co., Perkasie, Pennsylvania.

Figure 42. Spectral transmission curves of FRP laboratory samples. Violet and pink samples A, Filon Corporation; Violet and pink samples C, Structoglas Incorporated.

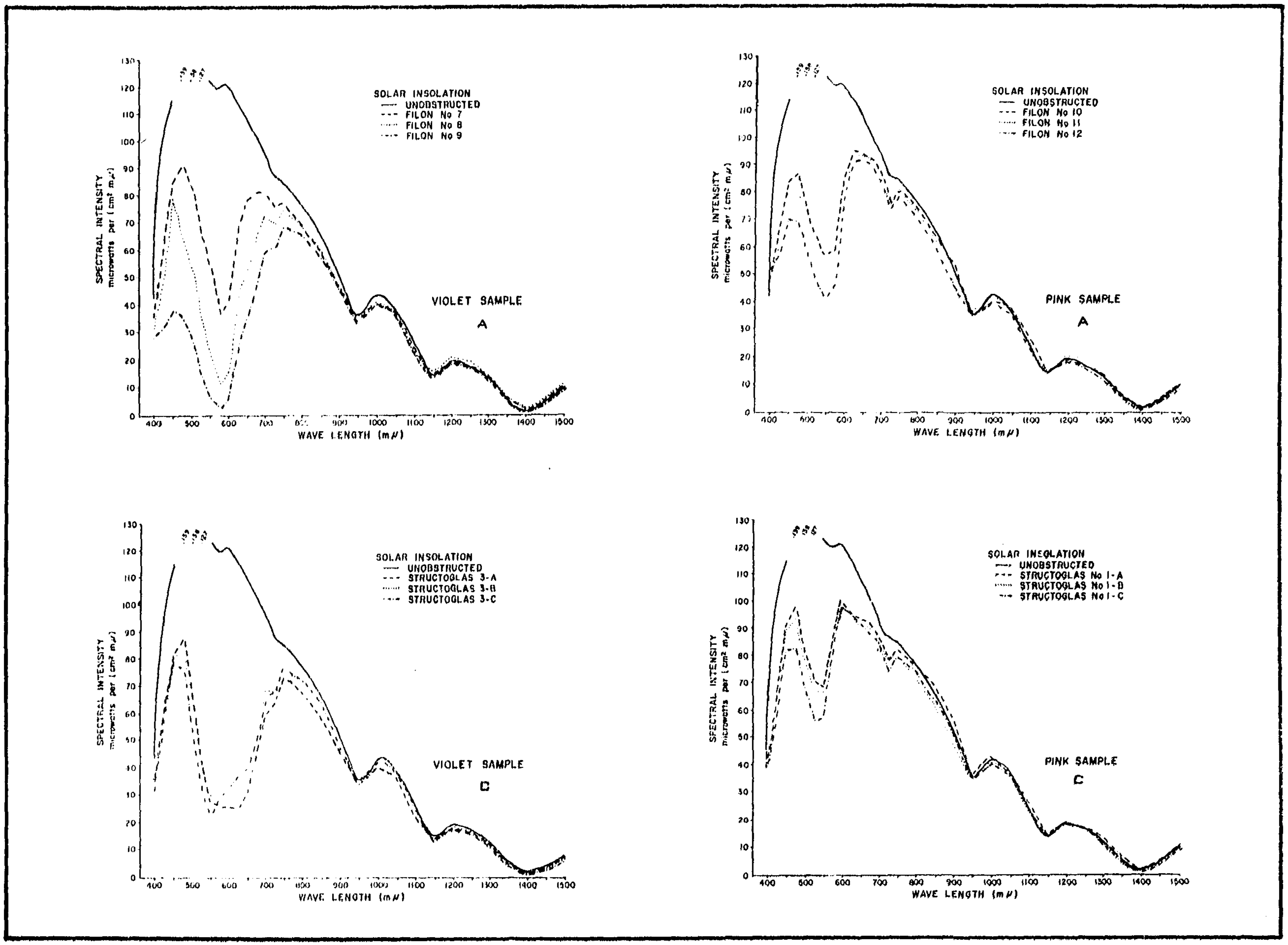

SOLAR INSOLATION
UNOBSTRUCTED
FILON No 7
FILON No 8
FILON No 9
VIOLET SAMPLE
A
SOLAR INSOLATION
UNOBSTRUCTED
FILON No 10
FILON No 11
FILON No 12
PINK SAMPLE
A
SOLAR INSOLATION
UNOBSTRUCTED
STRUCTOGLAS 3-A
STRUCTOGLAS 3-B
STRUCTOGLAS 3-C
VIOLET SAMPLE
B
SOLAR INSOLATION
UNOBSTRUCTED
STRUCTOGLAS No 1-A
STRUCTOGLAS No 1-B
STRUCTOGLAS No 1-C
PINK SAMPLE
C
SPECTRAL INTENSITY
WAVE LENGTH (mμ)

Figure 43. Spectral transmission curves of laboratory samples. Blue sample A, Filon Corporation; Blue sample B, Lasco Industries; Blue sample C, Structoglas Incorporated.

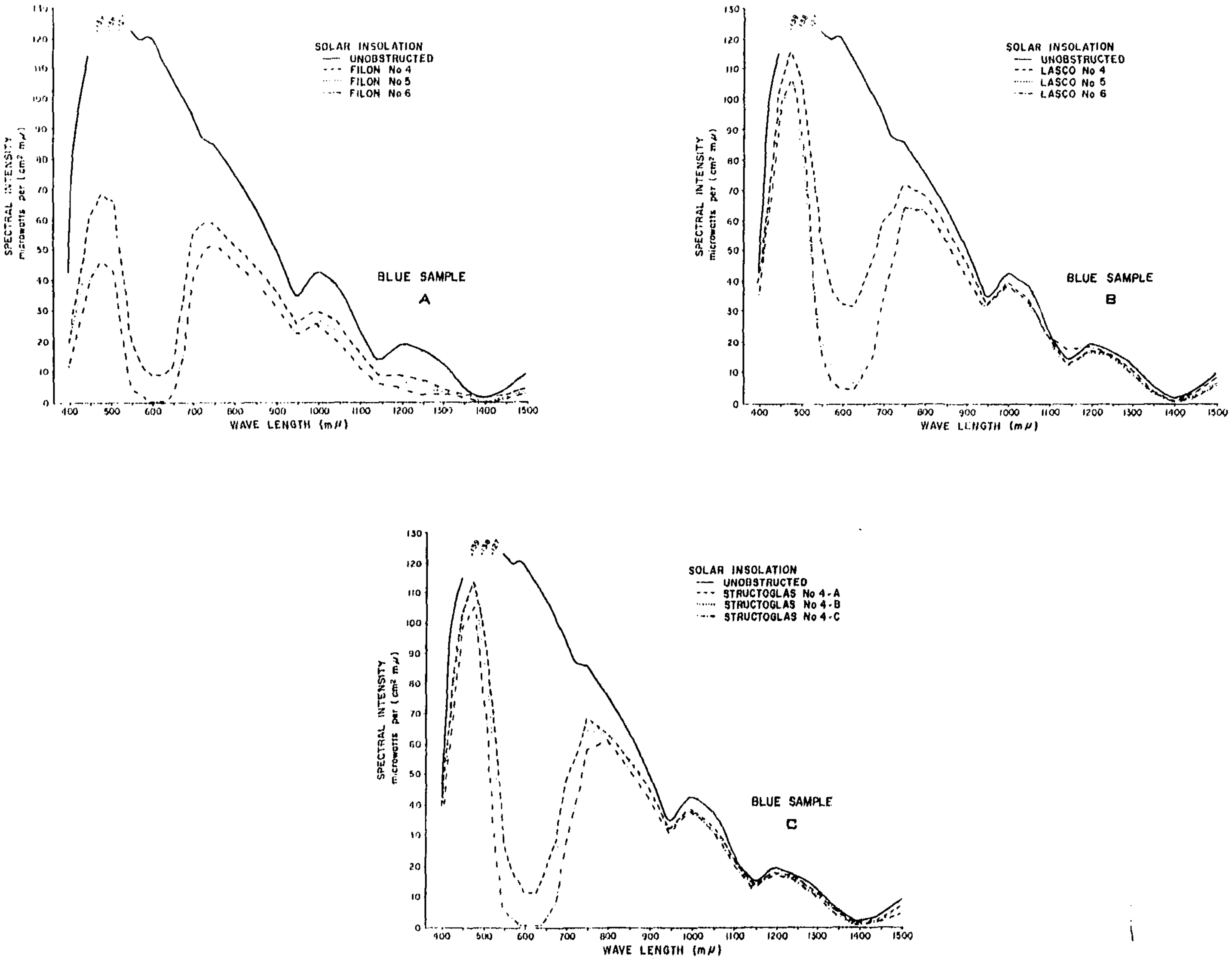
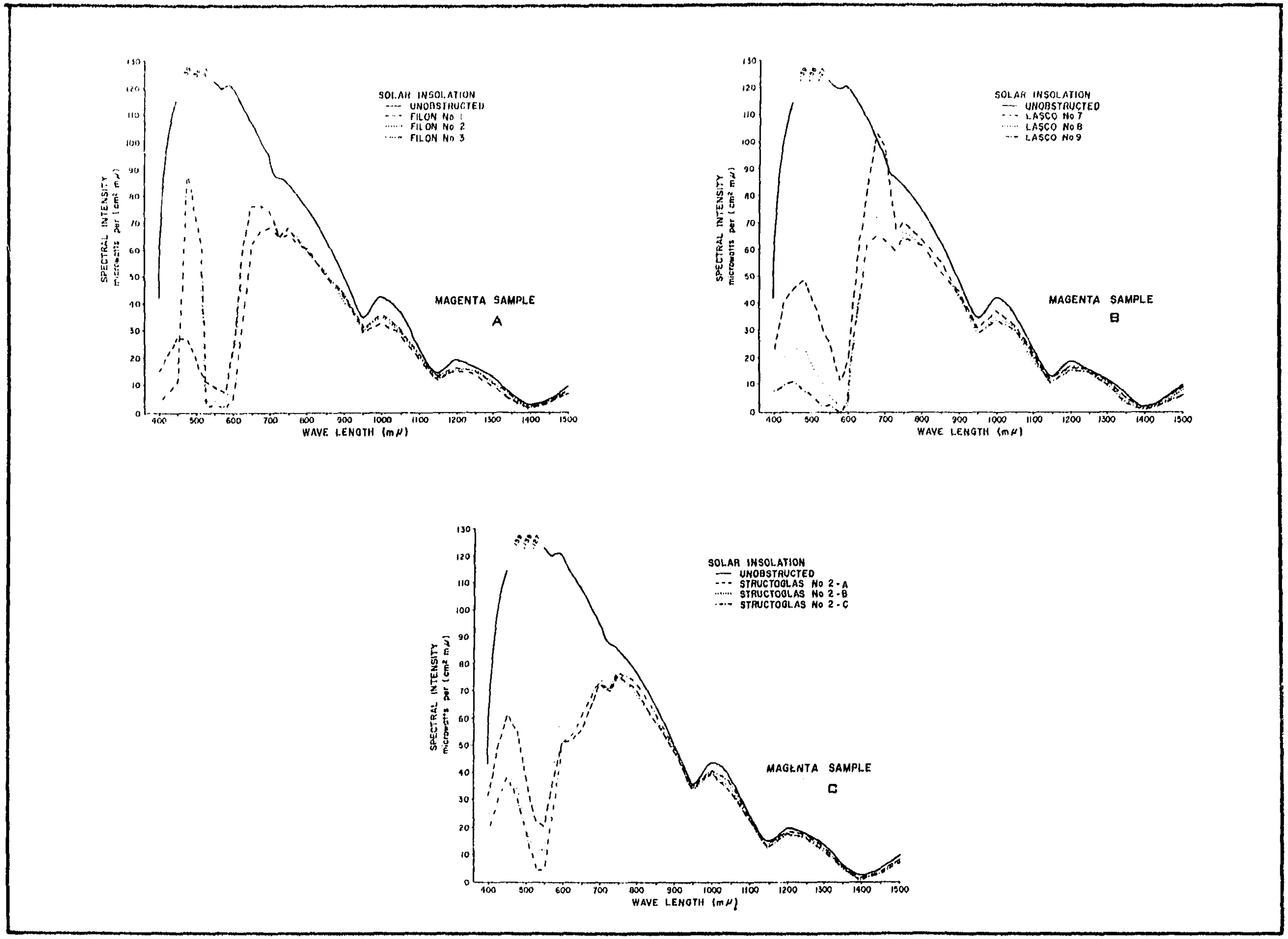

SOLAR INSOLATION
UNOBSTRUCTED
FILON No 4
FILON No 5
FILON No 6
BLUE SAMPLE
A
SOLAR INSOLATION
UNOBSTRUCTED
LASCO No 4
LASCO No 5
LASCO No 6
BLUE SAMPLE
B
SOLAR INSOLATION
UNOBSTRUCTED
STRUCTOGLAS No 4-A
STRUCTOGLAS No 4-B
STRUCTOGLAS No 4-C
BLUE SAMPLE
C
SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)

Figure 44. Spectral transmission curves of laboratory samples. Magenta sample A, Filon Corporation; magenta sample B, Lasco Industries; Magenta sample C, Structoglas Incorporated.


SOLAR INSOLATION
UNOBSTRUCTED
FILON No 1
FILON No 2
FILON No 3
MAGENTA SAMPLE
A
SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)
SOLAR INSOLATION
UNOBSTRUCTED
LASCO No 7
LASCO No 8
LASCO No 9
MAGENTA SAMPLE
B
SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)
SOLAR INSOLATION
UNOBSTRUCTED
STRUCTOGLAS No 2-A
STRUCTOGLAS No 2-B
STRUCTOGLAS No 2-C
MAGENTA SAMPLE
C
SPECTRAL INTENSITY
microwatts per (cm² mμ)
WAVE LENGTH (mμ)

$c^{1,2}$ air circulating fan
blade - 450 CFM, ¼ in. bore, stock no. 2C556
motor - 1/50 HP, 1500 rpm, 115V, stock no. 3M045

$d^{1,2}$ heater - Tital Dual Range, 4500/5600 BTU's. stock no. 2H934

$e^{1,2}$ damper motor - 115V, stock no. 2C831

f^{2} pressure relief louver - 19¼ in., stock no. 2C520

g evaporative cooler - 1725/1140 rpm, 2 speed, 6500/4330 CFM, 3/4 HP, 115/230/60/1 ph. - local source.

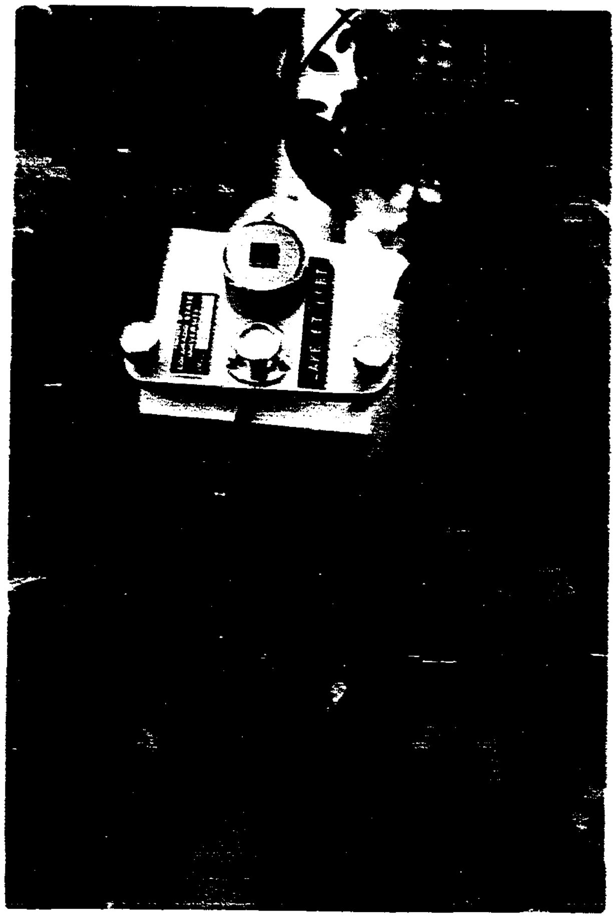
Sensing equipment The equipment used to measure transmissivity and surface temperatures in both parts of the investigation are shown in Figures 45, 46 and 47. The SR spectroradiometer sensing unit was placed at flower height when transmission data were collected during part I of the investigation (Figute 48).

Facilities

The Spectral Transmission Laboratory designed and constructed for part II of the investigation is shown in Figure 49. Plant material and equipment were positioned the same in all compartments (Figure 50).

Figure 45. Yellott Sol-a-meter (pyranometer) used to measure heat energy transmitted by the various covers.

Figure 46. Barnes infrared thermometer being used to measure the surface temperature of black and white construction paper.



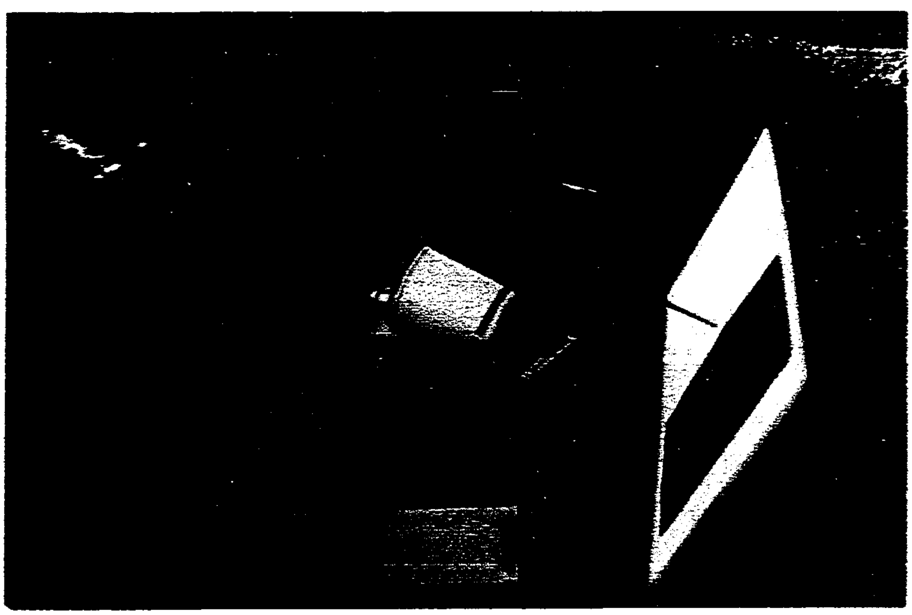


Figure 47. Model SR and SRR ISCO spectroradiometer being used to measure transmission characteristics of fiberglass reinforced plastic panels.

Figure 48. SR spectroradiometer sensing unit positioned for measurement of transmitted energy.

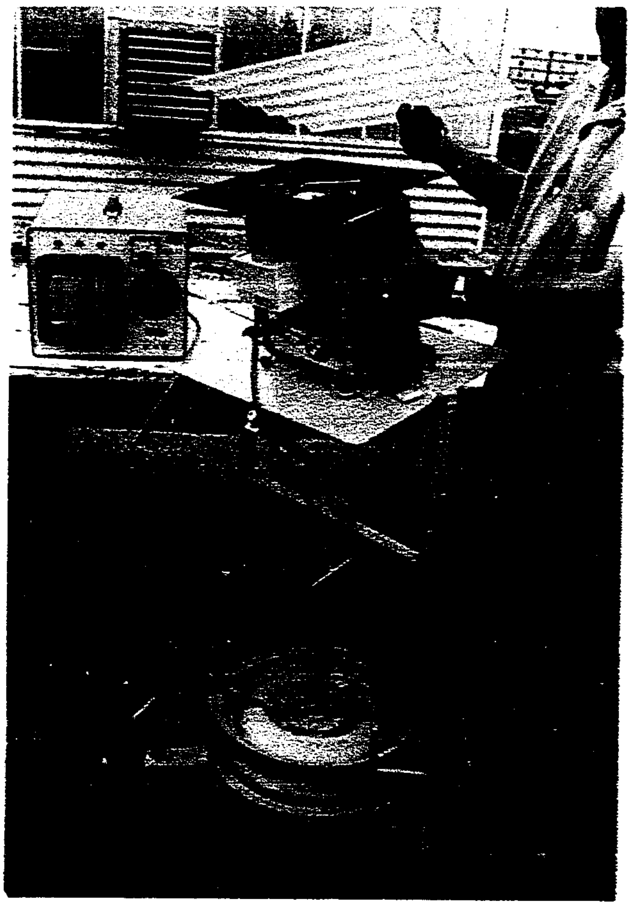
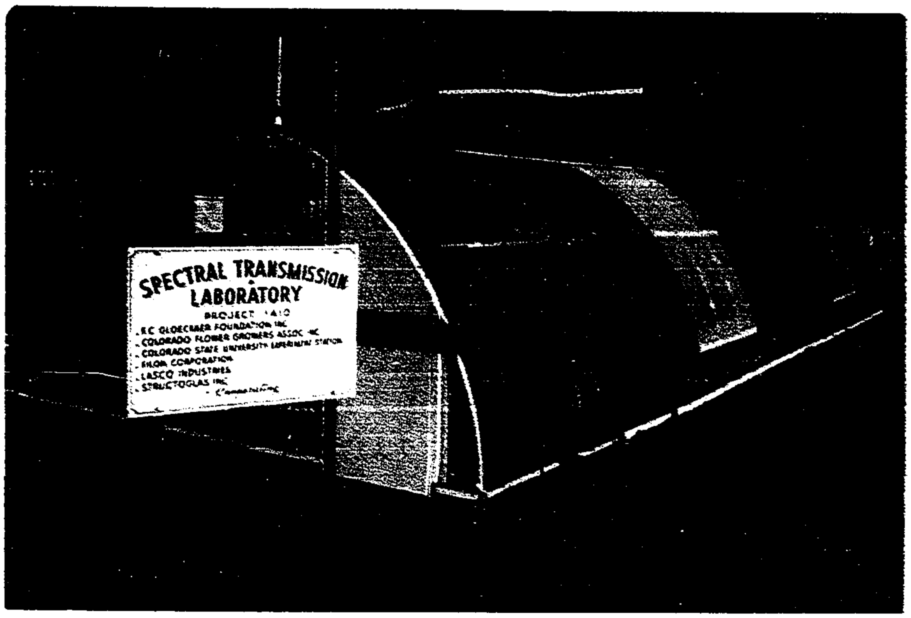


Figure 49. Spectral transmission laboratory designed for evaluating FRP covers.

Figure 50. Thermostat holder, pyranometer and plants inside the compartment covered with pink FRP panels.


SPECTRAL TRANSMISSION
LABORATORY
COLORADO FLOWER GROWERS ASSOC. INC
LASCO INDUSTRIES
STRUCTOGLAS INC