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A METHOD FOR REDUCING THE INFRARED RADIATION OR CHANGING THE SPECTRAL DISTRIBUTION OF SUNLIGHT IN GREENHOUSES

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NILSEN S., DONS C. and PETTERSEN H. *A method for reducing the infrared radiation or changing the spectral distribution of sunlight in greenhouses.* BIOTRONICS **13**, 1–9, 1984. Leaf and room temperature within a greenhouse irradiated with sunlight was controlled by using an infrared absorption layer of copper salts or water. Greenhouses made of acryl plates, which are used to reduce heat loss during winter, provided a practical system for testing the effect of infrared absorbing solutions. It was also possible to provide CO_2 enrichment during the entire light period in greenhouses with this type of cooling system, because it was not necessary to ventilate them. Both the leaf and the room temperatures could be reduced in these greenhouses as compared with conventional type greenhouses. Tomato and lettuce plants were increased in growth and yield. Flower initiation and quality of other crops were also enhanced.

INTRODUCTION

Sunlight can be divided into ultraviolet light (200–380 nm), visible light (380–760 nm) and infrared light (760–1400 nm). The photobiologically active region (200–1000 nm) is the most important for higher plants. Photosynthesis takes place at 400–700 nm and the phytochrome system, which controls plant development, has an absorption spectrum between 250 and 800 nm. Infrared light (IR), however, contributes little to plant growth and development, and causes overheating of plants cultivated in greenhouses. To prevent overheating, greenhouse temperatures must be controlled. Several methods have been used. Often greenhouses are ventilated and/or transparent surfaces are whitewashed. Now that CO_2 enrichment is an acceptable method for increasing growth and yield (*3*), and especially since it is best to provide CO_2 enrichment during the entire light period (*1*), the demand to keep greenhouses airtight during sunny days will increase.

Many Phytotron greenhouses are equipped with a system of roofsprays, which spray tap water or cooled water over greenhouse roofs along with an air condition temperature control unit. This method is used by The Biotron Institute in Japan and in The Phytotron, CNRS, France. Cooling systems using fluids which absorb IR-radiation have been described previously (*2*, *4*, *8*). The fluids are aqueous dyes or copper solutions, which are passed over or through the roof and then cooled before being recycled. The roofspraying method only makes a thin film of fluid. Since the absorption of IR-radiation is dependent upon the thickness of this layer, the roofspray method is inefficient, and the greenhouse would still require ventilation.

Most of new greenhouses in Norway are made of double acryl plates with 13 mm space between them. These double acryl plates, which have been used mainly to keep the heatloss to a minimum, reduce the energy used for winter heating by 50% (*7*). The space between the plates makes it possible to circulate a light absorbing fluid through these and increase the thickness of IR absorbing layer. An aqueous solution of $CuSO_4$ (*6*) or $CuCl_2$ (*9*) has been shown to considerably reduce the infrared radiation of sunlight. In this investigation $CuSO_4$ solution or water was circulated through acryl plates of greenhouses during cultivation experiments in a commercial size and a small, hobby size greenhouses.

The results from these preliminary experiments are discussed in relation to their effectiveness in reducing the room temperature, leaf temperature, increasing yield and the possibility of adapting this system for practical use.

MATERIAL AND METHODS

The greenhouses

Small greenhouses. Three greenhouses (5 m^2, volume 10 m^3) were constructed. House A (control) was made of aluminum frame covered with glass and ventilated automatically by openings (0.25 m^2) in the roof and door when the room temperature exceeded 18°C. House B was constructed in the same way as House A, but the glass connexions were sealed with silicone rubber and an air conditioning system was used to maintain the room temperature at the same level as in House A or at a designated temperature. House C had the same basic aluminum framework as the other greenhouses, but 16 mm double acryl plates were used instead of glass. The space between the plates was 13 mm and an aqueous solution of $CuSO_4$ (0.5%) or water was circulated through these spaces at a speed of 900 $l\,hr^{-1}$. The total volume of the space between the plates was 250 *l*. A heat exchanger cooled with tap water kept the circulating $CuSO_4$ solution cool. The heat exchanger was activated by a magnetic valve located in the tap water pipe and connected to a temperature control device. When water was circulated instead of $CuSO_4$ solution, a semiclosed system was made where tap water (8°C) could be introduced when the house temperature exceeded a certain level. Figure 1 shows the basic design of the three greenhouses with CO_2 injection and control, cooling and temperature control systems.

Commercial greenhouses. A greenhouse 150 m^2 made of 16 mm double acryl plates with $CuSO_4$ solution (1.5%) circulating through them was built in 1983 at Gjennestad Agricultural School (Fig. 2). The $CuSO_4$ solution was cooled by a heat exchanger connected to tap water (10°C). The $CuSO_4$ was circulated only when room temperature exceeded 18°C during the day, otherwise the plates were empty. The $CuSO_4$ solution was stored in an underground tank. A greenhouse made of double acrylic plates, but with normal roof ventilators was built and used as the control house.

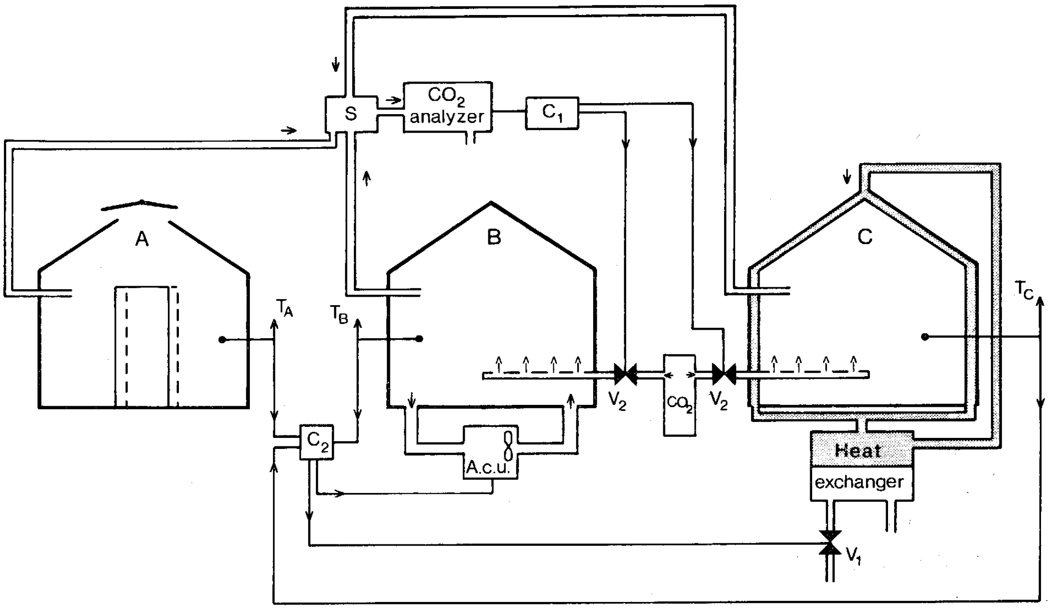

Fig. 1. Basic design of small hobby type greenhouses (5 m^2). House A was covered with glass and ventilated by openings in the ceiling and door. House B was covered with glass sealed with silicone to make it airtight. House C was covered with double acryl plates with fluid circulating through them (shaded area). The CO_2 injection valves V_2 was controlled by a CO_2 analyser and a CO_2 control unit C_1. The temperature control unit C_2 regulated the valve V_1 to the heat exchanger in House C and the air condition unit (A.c.u.) in House B. (S) gas switching unit.

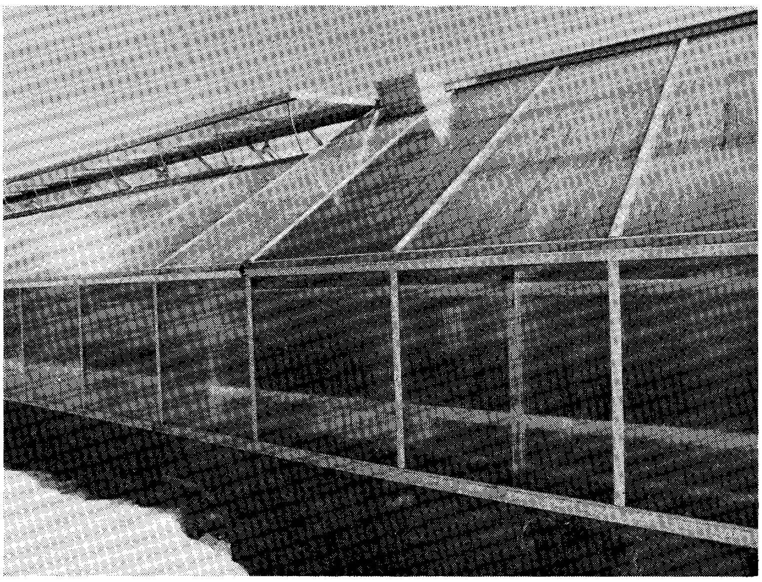

Fig. 2. Commercial greenhouses (150 m^2) covered with double acryl plates. To the right a house without ventilation, but with 1.5% $CuSO_4$ circulating through the plates. To the left control house with roof ventilators open.

Plant material

Tomato plants (cultivar 'Virosa') and lettuce (cultivar 'Salina') when cultivated in small greenhouses were grown in rockwool blocks placed in gulleys with circulating nutrient solution (*5*). Plants cultivated in commercial greenhouses and/or used for leaf temperature measurements were grown in peat/soil mixtures and watered/fertilized by the drip water method or by hand watering.

Leaf temperature measurements

Copper-constantan thermocouples were used to measure the leaf temperature of *Pelargonium zonale* (*6*). Lettuce leaf temperature was measured with a digital infrared thermometer (Barnes Model 14-2200-15) with a measurement area of 5 cm^2 and distance of 22 cm. Reproducible measurements were within the limit of ± 0.5°C.

Temperature control

The temperature was measured in the small greenhouses with thermocouples and these measurements were used to regulate the system. During the night when the temperature dropped considerably, an 800 W heater with fan was used to keep the temperature at a desirable level.

The temperature of the commercial greenhouse was measured at several points in the room and in the cooling system and these measurements were collectively recorded on a tape recorder.

CO_2 regulation

The CO_2 concentration was maintained at 1000 ± 200 μl CO_2 l^{-1} in Houses B and C and at ambient level (330 μl CO_2 l^{-1}) in House A. Liquid CO_2 provided by Norsk Hydro was passed over two electric valves regulated by a CO_2 analyser (URAS II, Hartman & Braun) and injected into the greenhouse.

The commercial greenhouse was also enriched with CO_2 (1000 ± 200 μl $CO_2 l^{-1}$) during the day by a similar method. The control greenhouse was enriched with CO_2 when the roof ventilators were closed.

Relative humidity

The relative humidity was recorded once a day with a sunshaded calibrated hygrometer.

Light transmission curve

The transmission and absorption properties of cooling solutions and acryl plates were recorded by a spectrophotometer (Shimadzu MPS 5000). Air was used as 100% transmission.

RESULTS AND DISCUSSION

In order to evaluate the simplest and most well known of the IR-absorbing fluids, $CuSO_4$ and $CuCl_2$ solutions, the light transmitting properties of these solutions at several concentrations was determined. The results in Fig. 3 show that $CuSO_4$ solutions as low as 0.5% reduced transmission in the infrared region by 50%, and showed only a 25% reduction at 660 nm, that part of the spectrum where plants are most active photosynthetically. The $CuCl_2$ solution had approximately the same absorption properties as $CuSO_4$. Water shows almost no absorption be-

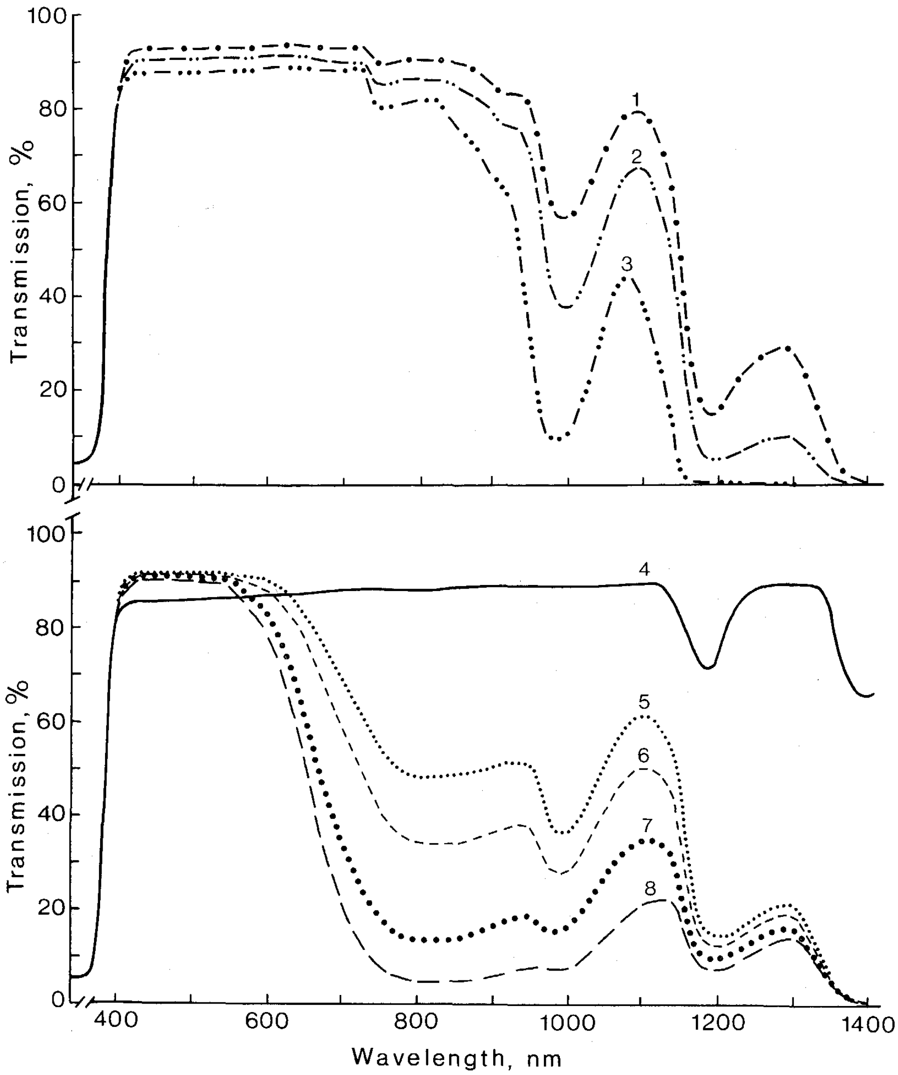

Fig. 3. The percent transmission of light at different wavelengths through double acryl plates filled with (1) 10 mm water; (2) 20 mm water; (3) 50 mm water; (4) air; (5) 13 mm 0.5% $CuSO_4$; (6) 13 mm 0.5% $CuCl_2$; (7) 13 mm 1.5% $CuSO_4$; (8) 13 mm 1.5% $CuCl_2$.

Table 1. Comparison of room temperature, humidity and leaf temperature of lettuce in a glass greenhouse cooled by ventilation (House A) with that in a double acryl plate greenhouse cooled with water (House C).

House A				House C			
Temperature (°C)			Relative humidity (%)	Temperature (°C)			Relative humidity (%)
Leaf T_1	Room T_2	T_1-T_2		Leaf T_1	Room T_2	T_1-T_2	
28.1	35.5	−7.4	29	30.8	27.0	3.8	42
28.2	35.5	−7.3	29	36.1	27.0	9.1	42
27.0	31.0	−4.0	37	29.3	29.0	−0.2	45
25.9	26.7	−0.8	34	26.7	28.0	−1.3	53

Table 2. Comparison of room temperature and leaf temperature of *Pelargonium zonale* in glass greenhouse cooled by ventilation (House A) with that in a double acryl plate greenhouse cooled with aqueous $CuSO_4$ solution (House C). The data represent 16 measurements made during a 15-min period. Standard deviation was ±1.0 or less.

House A			House C		
Temperature (°C)			Temperature (°C)		
Leaf T_1	Room T_2	T_1-T_2	Leaf T_1	Room T_2	T_1-T_2
37.5	31.5	6.0	28.5	25.0	3.5

Table 3. The effect of CO_2 enrichment (1000 μl CO_2 l^{-1}) and method of cooling on growth and yield of tomato and lettuce plants. House A was roof ventilated; House B was cooled with an air condition unit; House C was cooled by using either (a) 0.5% $CuSO_4$ or (b) water (8°C).

	House A glass	House B glass CO_2 enriched	House C acryl CO_2 enriched
Fresh weight (kg) (tomatoes/plant)	3.0±0.9	3.9±0.7	4.0±0.7 (a)
No. tomatoes/plant	57.0±15	70.0±13	83.0±12 (a)
Fresh weight (g) per lettuce	65	105	127 (b)

tween 400 and 700 nm, but it strongly reduces transmission above 800 nm. By increasing the thickness of the fluid layer it is possible to increase the IR-absorption of water without decreasing the photosynthetically active radiation (Fig. 3). The measurements performed here are indicative of the potential of this method. Many parameters could be changed to adapt this system to the local climate or availability of cooling facilities for the circulating fluid or availability of water/sea water as circulating fluid, as well as the design of the greenhouse.

The effect of water absorption of IR-radiation on leaf temperature (Table 1) as compared with $CuSO_4$ (Table 2) was quite different. The leaf temperature and the room temperature were about the same in the acryl plate greenhouse with $CuSO_4$ solution. However, the leaf temperature in air conditioned control greenhouse was significantly lower than that in the closed house with water circulation.

When using $CuSO_4$ solution a heat exchanger and a cooling system are needed. $CuSO_4$ is also toxic to plants, therefore all sealings must be tight, which may result in practical problems. However, as indicated here, it is possible to operate an ordinary greenhouse with $CuSO_4$ without polluting the plants or the cooling water of the heat exchanger. Even though some of photosynthetically active radiation was absorbed by the $CuSO_4$ cooled greenhouse (17–25% lower light), the yield of tomatoes was better than in the control greenhouse (Table 3). The higher air velocity in the control greenhouse, which was caused by the air conditioning system, should have increased plant growth, because of a reduction in the boundary layer and an increase in transpiration.

Fig. 4. "Scheffleria," one of the plants grown in the commercial greenhouse covered with double acryl plates is shown. Left: plant from house with infrared absorbing $CuSO_4$ (1.5%) and no ventilation. Right: plant from control house with roof ventilation.

Table 4. Representative measurements during summer 1983 on sunny days in a commercial acryl plate greenhouse (150 m^2) cooled with 1.5% $CuSO_4$ and a control house with normal roof ventilation.

Time	Radiation (W/m^2)	Air temperature (°C)			Fluid temperature (°C)			
		Out-side	Acryl house	Control house	Cooling water to heat exchange		$CuSO_4$ solution to heat exchange	
					In	Out	In	Out
7/7, 1400 hr	743	23.4	34.6	30.3	10.0	22.1	26.8	17.5
11/7, 1400 hr	709	26.0	34.8	32.1	9.8	21.9	26.8	17.3
11/7, 2000 hr	117	21.3	27.6	25.8	9.6	17.1	19.9	14.4
13/7, 1430 hr	690	29.4	33.9	33.1	9.9	20.1	26.3	16.1

Table 5. Comparison of temperature and humidity inside and outside different greenhouses (5 m^2) during two 20-day growth periods of lettuce.

	Outside temp.	House A (glass) (ventilation)	House B (glass) (air cooled)	House C (acryl) (water cooled)
Mean maximum temperature (°C)				
June	19	30	31	29
July	25	33	33	30
Relative humidity (%)				
June	57	47	49	65
July	57	61	68	66

Lettuce and flowers cultivated in a commercial acryl plate greenhouse (150 m^2) cooled with $CuSO_4$ solution (1.5%) during the spring of 1983 obviously grew faster than plants grown in the control greenhouse, although no direct measurements were made. The control greenhouse was enriched with CO_2 when the roof ventilator was closed, while the $CuSO_4$ cooled greenhouse was enriched with CO_2 during the entire light period, which makes comparisons almost impossible. However, it was observed that the development time was reduced and flower initiation was stimulated, which resulted in plants with a higher sales quality (Fig. 4). This stimulation of flower initiation might be due to the increased red/infrared ratio.

The use of a large and a small greenhouse with surface/volume ratio that was quite different provided the opportunity to study different aspects of cooling due to infrared absorption as compared with cooling caused by the low temperature of the roof/walls. The 0.5% $CuSO_4$ solution used for cooling the small greenhouse, entered the plates at a temperature of 20°C and reached 24°C upon leaving on sunny hot days (*6*) and the resulting room temperature was 30°C, while in the commercial greenhouse the $CuSO_4$ solution (1.5%) entered the house at approximately 17°C and the resulting room temperature was 34°C. The temperature of the commercial greenhouses during 1983 was continuously recorded and some representative measurements are shown in Table 4. It is clearly demonstrated that on sunny days the room temperature of the airtight acryl plate greenhouse with 1.5% $CuSO_4$ solution only slightly exceeded the control greenhouse.

When water was the circulating fluid, the room temperature never exceeded 30°C (Table 5). This was probably due mainly to the low temperature of the water (8°C), since the absorption of IR-radiation by water was much less than $CuSO_4$ solution (Fig. 3). Even though the room temperature in the water cooled greenhouse was closer to optimal growing conditions, leaf temperature could be reduced more by better filtration of IR-radiation. The measurements of room temperature and humidity during two periods with different mean maximum temperatures is shown in Table 5. The room temperature of the acryl plate greenhouse was slightly lower than in the ordinary ventilated greenhouse, even though the acryl house was kept air tight during the entire day. The relative humidity was higher in the acryl house than in the control greenhouse of glass. Lettuce grown in the water cooled greenhouse showed a significant increase in plant fresh weight (Table 3).

At present acryl plates are only available in a few dimensions, but it is easy to make them in different thicknesses, and by the method used in the commercial greenhouse it is possible to seal the ends and make an inlet and outlet for the circulating fluid. As indicated here both water and other more effective infrared absorbing fluids can be used. However, what is most important is the type of system used to cool the circulating fluid. In some cases it may be more practical to use a fluid such as water which does not need to be recirculated. For example, in hot climates where sea water is available, sea water from a low depth might be used directly as a circulating fluid and at a thickness sufficient to keep the leaf temperature at a satisfactory level. Furthermore, solutions that absorb different parts of the visible spectrum could be used for circulation. This would provide the possibility to cultivate plants on a large scale in selected wavelengths of light at high photon flux density, which would be useful in studies of wavelength effect on control mechanisms for development and the selective excitation of the photosystems.

REFERENCES

1. Calvert A. and Slack G. (1976) Effect of carbon dioxide enrichment on growth, development and yield of glass house tomatoes. II. The duration of daily periods of enrichment. *J. Hortic. Sci.* **51**, 401–409.
2. Chiapale J. P., Damagnez J., Denis P. and Jourdan P. (1976) La serre solaire. 12e Colloque National des Plastiques en Agriculture. Hyères. *Comité des Plastiques en Agriculture*, 87–90.
3. Kramer P. J. (1981) Carbon dioxide concentration, photosynthesis, and dry matter production. *BioScience* **31**, 29–33.
4. Morris L. G., Trichet E. S., Vanstone F. H. and Wells D. A. (1958) The limitation of maximum temperature in a glasshouse by the use of water film on the roof. *J. Agric. Eng. Res.* **3**, 121–130.
5. Nilsen S., Hovland K., Dons C. and Sletten S. P. (1983) Effect of CO_2 enrichment on photosynthesis, growth and yield of tomato. *Scientia Hortic.* **20**, 1–14.
6. Nilsen S., Dons C. and Hovland K. (1983) Effect of reducing the infrared radiation of sunlight on greenhouse temperature, leaf temperature, growth and yield. *Scientia Hortic.* **20**, 15–22.
7. Sebesta Z. and Reiersen D. (1980) Heat consumption and climatic conditions in a greenhouse covered with double acryl plates as compared to single glassing. *Meld. Norg. Landbrukshoegsk.* **59** (9), 2–20.
8. Van Bavel C. H. M. and Damagnez J. (1978) A simulation model for energy storage and savings of a fluid-roof solar greenhouse. *Acta Hortic.* **76**, 229–236.
9. Weichman F. L. (1981) Channelled plastic for greenhouse and skylight use. *Solar Energy* **27**, 571–575.