RECENT DEVELOPMENTS IN GREENHOUSE COOLING, VENTILATION, INSULATION AND AIR POLLUTION CONTROL

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Several research projects conducted at the University of California Agricultural Experiment Station at Riverside required greenhouse facilities which have reasonably narrow temperature controls and air purification systems for protecting plants against smog damage. This report describes the application of some innovative equipment, both old and new, which have not been generally used in greenhouse facilities but which appear to be superior to "standard" greenhouse components.

Greenhouse Cooling. Cooling is essential at Riverside where summer dry bulb temperatures exceed 100°F several days per year. The standard evaporative cooling system available from greenhouse manufacturers utilize vertical excelsior pads and exhaust fans. Disadvantages of the vertical (upright) pad systems are:

1. After a few months use, voids develop in the pads which allow uncooled air to move into the greenhouse, thereby reducing the cooling efficiency of the system.
2. To maintain reasonable efficiency, pads must be changed at least annually and frequently more often.

A horizontal (flat) evaporative pad system was designed by W.T. Welchert and Frank Wiersma, Agricultural Engineers at the University of Arizona at Tucson about 1970-71.

Field observation indicated the following advantages and disadvantages of the horizontal pad orientation over the vertical pad system:

Advantages are:

1. Dust accumulation in the pad is greatly reduced; hence, air flow resistance is more constant, pad cleaning time is eliminated and pad life substantially prolonged.
2. Pad sag and air leakage around the frame is eliminated.
3. Pad cost is reduced because bulk excelsior can be used instead of hand or machine packed pads.
4. Easy access simplifies pad replacement and maintenance.
5. Pad area is not limited to available vertical wall space.
6. Light control and wall closing systems are simplified.
7. Multi-level pad cabinet arrangements permit design of multi-stage cooling and winter ventilation control.

Disadvantages are:

1. Low-volume nozzles require more water filtering than drip pipes.
2. Multi-level systems may require additional baffling to prevent the pick-up of free water in the air passing up through alternate pads.

In 1975, Benham and Wiersma conducted extensive testing to compare the relative efficiency of the two systems (2). The testing showed that the horizontally oriented evaporative pads were from 10% to 20% more efficient.

We have incorporated the horizontal pad design into several of our greenhouses and have been highly satisfied with the reliability of the system, the low maintenance and the extended period between pad changes.

Air Purification. A second requirement for our research greenhouse is a system of air filtration for the removal of the plant damaging components of "smog." Without activated carbon filters, we can experience a complete loss of such crops as tomatoes, due to smog. The removal of photochemical, phytotoxic air pollutants is accomplished by using horizontal trays of activated carbon. Either activated coke carbon or coconut hull charcoal may be used.

Manufacturered carbon filters available through trade sources are quite expensive. The horizontal tray is less costly and is the best solution to reliable prevention of smog injury to sensitive plants.

The first application of activated carbon filters to purify incoming greenhouse air was made at Cal Tech's Earhart Plant Research Laboratory in 1951. A second such installation was made in one of the greenhouses at U.C. Berkeley in 1969. U.C. Riverside now has three greenhouses with this type of air filters installed. No smog damage has occurred since their installation.

Basic design for carbon filters are:

1. Thickness of activated carbon bed: 1" to 1-1/4".
2. Pounds of activated carbon per 1,000 CfM of air flow: 60.
3. Face velocity of air through carbon bed: 50 ft. per minute, which provides air contact with activated carbon of 0.10 to 0.13 seconds.

Horizontal evaporative cooling pads and carbon filter trays can be constructed in a serial arrangement in an "air conditioning chamber" to provide purified cool air to a greenhouse operation.

Reducing Heat Losses. Reducing heat losses in greenhouses has become an important economic consideration as fuel costs have increased. The research by Simpkins and Roberts (3) on the use of curtains to reduce heat loss from double-filmed air-inflated polyethylene greenhouses indicate that substantial heat savings can be obtained. Their data suggest savings of up to 50% of the total heat requirement could be achieved by certain curtain materials and installation techniques.

Tests were conducted on a small greenhouse, 3.3 m wide × 4.9 m long × 1.8 m high, at the eaves, with a 6:12 roof pitch. Although the data developed from the small greenhouse may not apply to a full size operating greenhouse, their results do provide a basis for predicting possible heat savings.

The small greenhouse was completely covered, roof and walls, with an air inflated double film of 6 mil, Monsanto 602 polyethylene. Various curtain materials and installation techniques were compared for heat conservation characteristics.

Prior research had established that the double, air-inflated roof and walls reduce fuel consumption by approximately 30% compared to single wall polyethylene or fiberglass.

The reduction in heat loss reported by Simpkin and Roberts was in addition to that saved by the double layered cover. A portion of their data is tabulated in Table 1.

Curtain materials consisted of clear polyethylene film, black polyethylene film and aluminized mylar film. In addition, fiberglass insulation and condensation were evaluated.

Installation techniques compared were:

1. Curtains installed under and parallel to the roof surface.
2. Curtains attached at edges but not sealed.
3. Curtains from gutter to gutter to create "attic" space.
4. Curtains sealed at edges.
5. Curtains installed so they were in contact with the convex surface of the inflated roof or walls at the highest point of the bulge. This conformation was compared to installing the curtain with a 10 cm separation from the inflated cover, thereby creating an air space between cover and curtain.

Some generalizations which can be drawn from Simpkins and Roberts tests are:

1. Aluminized mylar is superior to black and clear polyethylene.
2. Black polyethylene is better than clear.
3. Sealing the edges is superior to unsealed.
4. Providing a dead air space of 10 cm between outer walls and curtain is better than curtain in partial contact at the bulge of inflated outer cover.

Table 1. Comparison of curtain materials and installation techniques on heat savings.

Curtain Material	Installation Techniques	Heat Savings, %
	Side Walls Only	
Fiberglass Insulation	On walls only	11
Black Polyethylene	Sealed at top	12
Clear Polyethylene	10 cm from wall - not sealed	13
Clear Polyethylene	In partial contact with wall - not sealed	21
Clear Polyethylene	10 cm from walls - sealed all sides	31
	Roof - 6:12 Slope	
Black Polyethylene	In partial contact with roof - not sealed at edges	20 - 25
Aluminized Mylar	In partial contact with roof - not sealed at edges	48
	Horizontal Roof	
Black Polyethylene	In partial contact with roof - not sealed at edges	28
Aluminized Mylar	In partial contact - not sealed at edges	55
	Ceiling Only	
Clear polyethylene	Gutter to gutter	37
Aluminized Mylar plus Clear Polyethylene	Gutter to gutter	44
	Roof Plus Sidewalls	
Black Polyethylene	Roof and sidewalls	12
Condensation only	No curtains	14
Black Polyethylene plus Aluminized Mylar	Roof and sidewalls	43
	Ceiling Plus Sidewalls	
Fiberglass Insulation Black Polyethylene	Fiberglass insulation on walls Black Polyethylene eave to eave	52
Fiberglass Insulation Clear Polyethylene in Curtain	Fiberglass insulation on walls Clear Polyethylene curtain eave to eave	57
Fiberglass Insulation walls, clear polyethylene plus aluminized Mylar	Fiberglass insulation on walls. Clear polyethylene, aluminized Mylar eave to eave	70

5. Ceiling curtains from gutter to gutter are better than curtains under and parallel to roof surface.

Opaque curtains such as black polyethylene or aluminized mylar must have mechanisms to extend them at night and roll them in during the day. Such mechanisms are used by chrysanthemum growers using black cloth application.

Clear polyethylene may be installed permanently at appreciably less cost. Although less effective than opaque curtains, clear polyethylene curtains can reduce heat loss by approximately 50%.

A review of fuel saving techniques being used by greenhouse operators in both the USA and Europe is in the October, 1976, issue of Growers Talks (1).

LITERATURE CITED

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SANITATION IN PLANT PROPAGATION

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In 1957, the *U.C. Manual 23, U.C. System for Producing Healthy Container-Grown Plants* (1) was published. It cost one dollar and was reprinted at least once. It is now out of print and in need of revision because of changes in pesticide registrations and other changes. But the information about plant diseases has not changed significantly. One section, "A Nursery Sanitation Code" by Kenneth Baker, is as good a guide now as it was 20 years ago. I would like to discuss this section explaining and commenting on the code which appears on pages 22 and 23.

There are two main sources of plant-disease causal organisms: infected plant parts, and infested soil. Reproductive or survival units (spores, sclerotia, etc.), referred to as inoculum, may be present in soil or produced on diseased plants. The inoculum can spread or be disseminated (transported) in various ways. A knowledge of the various dissemination methods will help the propagator understand the need for sanitation practices.