GREENHOUSE GLAZING MATERIALS: A COMPARISON

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Abstract.--This paper evaluates the most commonly used glazing materials for greenhouses, comparing their properties, performance characteristics, cost factors and heat loss.

Résumé.--Une évaluation des matériaux de vitrage les plus utilisés dans la construction de serres et une comparaison de leurs caractéristiques, leurs critères de qualité, des facteurs de coût et des pertes de chaleur sont présentées.

INTRODUCTION

A greenhouse, according to the World Book Dictionary, is "a building with a glass roof and glass sides, kept warm for growing plants". According to Webster's Third New International Dictionary, a greenhouse is "1) a glassed enclosure used for the cultivation or protection of tender plants; 2) a clear plastic shell covering a section of an airplane." At least Webster's definition alludes to a glazing product other than glass.

Today's greenhouses can be glazed with a variety of light-transmitting materials which fall into one of three categories: glass, flexible plastics and rigid plastics. The plastics can be further subdivided into generic materials such as polyvinyl chlorides, polyethylenes, polypropylenes, polycarbonates, acrylics and polyesters, to name a few. Research is continuing at the manufacturer's level in an effort to develop the "perfect" glazing material. Materials tested by independent laboratories, government agricultural agencies, and the greenhouse sector are usually compared with a standard which is "glass".

In this paper I shall attempt to compare the various glazing materials, discuss their pros and cons, and clear up some common misconceptions, particularly with regard to plastic glazing products.

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The selection of a glazing material must be based on two important factors: performance and cost. These are detailed below.

Performance factors:
- transmission (photosynthetically active radiation, between .4 and .7 1-1) and infrared (IR) wave-lengths
- insulation values R or U
- fire resistance
- expected service life
- weatherability/surface stability
- aging

Cost factors:
- initial cost of material
- installation
- maintenance
- replacement
- structural considerations
- availability

Numerous reports have been published dealing with the above factors and the ways in which each may influence the greenhouse growing environment. Heating, cooling, ventilation, plant response, etc., are all affected by the characteristics of the glazing material used. This paper will expose only the tip of the iceberg in outlining the basic properties of the various glazing materials.

GLASS

In North America, glass panes used in the greenhouse industry have evolved from a

width of 16 in.[2] to the 20-in. width used in the late 1950s and early 1960s to the 24-in. width used today. Some 30-in.-wide glass is also being used, usually for institutional greenhouses.

A single-glazed glass greenhouse is generally used as the "control house" for comparison of the results of crop growth response, light levels at plant height, energy consumption, etc., in greenhouses with other than glass glazing.

Performance Characteristics of Glass Used in Greenhouse Construction

- transmits 90% of available solar energy
- transmits penetrating IR (infrared) radiation but becomes impervious to nonpenetrating IR radiation at about 2.8 p
- overall thermal conductivity - U value = 1.1 BTU/hr/ft^2/°F
- heat transfer coefficient R = 0.88
- low impact resistance (Tempered glass has higher impact resistance than horticultural grade but is more costly.)
- noncombustible
- long life expectancy (dependent on local incidence of wind and hail)
- glazing bars required at approx. 61 cm centres
- requires yearly maintenance, resealing, caulking, etc. , to maintain air tightness
- can be sprayed with a shading solution to reduce heat between spring and fall

Cost

- ranges from \$7/m^2 for 24 oz. to \$9.15/m^2 for 32 oz. glass
- installed greenhouse cost ranges from about \$75/m^2 to \$108/m^2 of ground area, depending on whether the greenhouse is detached or gutter connected (These costs are based on an area of approx. 1800 m^2, and depend on the options installed.)

NOTE: All costs are quoted in Canadian dollars.

[2]Glass widths and thicknesses are given in English units because these are still in use in the industry.

PLASTICS

Plastics became an alternative to glass in the mid-1950s. Clarification of the characteristics and limitations of the different plastics currently available may provide a better understanding of these materials. Factors such as initial cost, light transmission values, weatherability, installed costs and frequency of maintenance are major considerations when one is choosing a specific plastic.

There are two categories of plastics used in the greenhouse industry: flexible or film plastics and rigid plastics. The second category can be further divided into thermoset and thermoplastic groups.

Flexible (Film) Plastics

Flexible plastics include polyethylenes (PE) and polyvinyl-fluorides, among others. The most widely used film in the greenhouse industry is PE, which is known by tradenames such as Monsanto 602 or C.I.L. Dura-Film. PE is a flexible and inexpensive material, available in thicknesses of 2 mil to 8 mil. The greenhouse industry generally uses 4 or 6 mil polyethylene. The film is manufactured in widths of up to 12 m and lengths of up to 46 m.

Polyethylene is not a permanent cover. Even with ultraviolet (UV) inhibitors the material will deteriorate after a period of outdoor exposure. This breakdown is caused primarily by the radiation in the sun's rays. It is recommended that the outer polyethylene cover be replaced every year, although some growers have found that they can get 18 to 24 months of use out of this material.

Heat loss in single-glazed greenhouses can be reduced by covering the glazed areas with either a single or a double layer of PE. Continuous positive air pressure within the greenhouse will inflate the layer of PE, raising it above the glass and, in effect, providing double glazing.

A double layer of PE, either over existing glass or as the primary glazing, is much easier to inflate. A small blower (1/30 H.P. for every 900 m^2 is recommended by one film manufacturer) will inflate the layers of PE. Flexible 10 cm diameter plastic hoses connect the various bubbles so that a uniform air pressure is maintained between the layers throughout the greenhouse cover.

Performance Characteristics of Double-layer UV-inhibited Polyethylene Used in Greenhouse Construction

- transmits 80% of available solar energy (88% for a single layer)
- quite permeable to the longer wavelengths of the thermal radiation spectra (This is one reason that PE houses cool off so quickly after sunset.)
- thermal conductivity: U value = 1.14 single, 0.7 double, R value = 1.43 double, 0.87 single
- the least durable covering material; has a maximum life expectancy of 18-24 months in our climate
- impact resistance twice as good as that of glass, although it is easily punctured by a sharp object (Small holes and cuts can be patched with a plastic-backed acrylic adhesive tape.)
- provides a more tightly sealed house than lapped glass
- minimum fire hazard
- can become brittle at low temperatures

Cost

- for UV-inhibited polyethylene film: 4 mil - \$.43 to \$.65/m^2, 6 mil - \$.65 to \$.86/m^2
- installed costs range from \$21.50 to \$32.00/m^2 for an 1800 m^2 complex, depending on options chosen
- reskinning of existing PE houses costs about \$.43 to \$.65/m^2 plus new film(s)
- PE-covered greenhouses are classified as high risk and underwriters are often reluctant to insure them.

Other flexible plastics such as polyvinyls and reinforced polyethylenes are not used extensively in North America. Life expectancy, size limitation and costs have prevented widespread acceptance of these plastics by the North American greenhouse industry.

Rigid Plastics

Both thermosetting (i.e., glass-reinforced polyesters - FRP or GRP) and thermoplastics (i.e., acrylic and polycarbonate) are available in rigid sheets.

Fibreglass-reinforced plastics: The use of FRP as greenhouse glazing material has declined in the last few years in southern Ontario. Corrugated or flat sheets are available in widths over 1.3 m and lengths up to 9 m. The sheets are made of fibreglass strands which are sandwiched between layers of polyester resin. The most common FRP panels used by the greenhouse industry are modified polyesters with 15% acrylic additives. These additives, along with a surface coating of polyvinyl-fluoride ("Tedlar"), have increased the life expectancy of the panels. Some manufacturers will guarantee replacement over a 15- to 20-year period. Some of the guarantees are prorated.

Performance Characteristics of FRP Used in Greenhouse Construction

- a single layer of FRP transmits 70% to 90% of available solar energy
- slightly higher IR transmission than with glass
- higher impact and sustained load-carrying capacity (two to four times that of glass)
- has a U value equal to that of single glass, U value = 1.1, R value = 1.00
- life expectancy of 10-20 years
- frequency of maintenance: a good cleaning yearly with a resurfacing recommended after 3-5 years
- a combustible material: insurance rates reflect replacment costs (2 1/2 to 3 times those of glass)
- special corrugated closure strips are required to seal at ridges, eaves, gutter, etc.
- structural support required at approx. 90-100 cm centres
- corrugated FRP sheets increase heat transfer surface area by 12% to 16% over that of flat sheets
- some tendency to discolor and erode on the surface after prolonged outdoor exposure

Cost

- 2.5 in. corrugated x 50.5 in. wide, 4 oz. about \$8.6/m^2, 5 oz. about \$9.7/m^2, flat fibreglass \$8.6 to \$9.7/m^2
- installed costs, for a greenhouse area of approx. 1800 m^2, depend on type of structure (gutter-connected or free-standing), options, etc., but range from \$59 to \$113/m^2.

Thermoplastic sheets: Although flat (monolithic) sheets of acrylic or polycarbonate formulation are available to the greenhouse operator they are rarely used because of their high cost, their deflection under load, and size restrictions. However, double-skinned (DSS) glazing

panels extruded from either acrylic or polycarbonate molding powders have been developed in the last 10 years. They have all the physical properties of the monolithic sheets with the added benefits of double glazing, light weight and the ability to withstand greater live loads before deflection.

The acrylic DSS (tradenames Acrylite SDP or Exolite, etc.) used in the European greenhouse market is either 8 mm or 16 mm in overall thickness. The North American market uses primarily the 16 mm sheet.

The polycarbonate DSS (tradenames Cyro-Ion SDP, Exolite, Tuffak-Twinwall, Qualex, Cartoplast, etc.) is available in thicknesses of 4 mm to 8 mm, 10 mm and 16 mm.

Performance Characteristics of Acrylic DSS Used in Greenhouse Construction

- transmits 83% to 85% of available solar energy
- becomes impervious to nonpenetrating IR at about 2.2p
- high strength, stiffness and impact resistance
- thermal conductivity 16 mm (the thinner DSS will be less insulative): U value = .55, R value = 1.82
- reduces energy loss by 35% to 62% in comparison with single-glazed glass greenhouse
- most weatherable of all the light-transmitting plastics; will not discolor, become brittle, etc.
- diffusion of light similar to that by FRP
- minimal shading effect as glazing bars are on 122 cm centres
- available in lengths up to 7.6 m, sufficient to span from eave to ridge
- very lightweight, only 4.9 kg/m^2 (16 mm) and 3.5 kg/m^2 (8 mm)
- minimal maintenance
- life expectancy 20+ years
- combustible, flame spread comparable with that of red oak, insurance rates equal to those for FRP

Costs

- \$32 to \$43/m^2, depending on quantity, for 16 mm thickness
- installed greenhouse costs about \$32/m^2 more than a conventional glass house of the same dimensions
- if used as gable and sidewall glazing only, the additional cost over that of a comparable glass house would be about \$11/m^2

Performance Characteristics of Polycarbonate DSS Used in Greenhouse Construction

- not as weatherable as acrylics, slight discoloration with age
- combustible: flame spread half that of acrylic DSS
- highly resistant to impact
- less rigid than acrylic DSS; requires more support
- can be bent to a radius minimum 1.2 m (6 mm) or 4.6 m (16 mm)
- available in widths up to 2.1 m and lengths up to 9 m.

Cost

- less expensive than acrylic DSS in the thinner sheets, ranging from \$16/m^2 to \$27/m^2
- the 16 mm sheet costs about \$16/m^2 more than the 16 mm acrylic DSS

CONCLUSIONS

The primary use of a glazed enclosure is "for the cultivation or protection of tender plants". It sounds so simple. In reality, a greenhouse must not only protect plants but also provide an environment conducive to plant growth; therefore, a light-transmitting shell is required. The glazing material used directly affects that growing environment. The shell must also have insulative properties to reduce operating costs. A comparison of the performance characteristics and cost factors listed here should enable the prospective purchaser to make a choice between the glazing materials currently available.