

Section 1

Greenhouse Lighting

Greenhouse Glazing

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Introduction

With the spring growing season just around the corner, it seems a good idea to review some of the issues surrounding glazing materials. Let's first look at some light (radiation) terminology. The radiation spectrum can be divided in several specific wavebands, which are defined by their range of wavelengths or energy content (e.g., radio and TV radiation, microwave radiation, visible light, etc.). The higher the wavelength, the smaller the energy content. Typically, the wavelength of light used by plants is expressed in the units of nanometer (nm; one billionth of a meter; a human hair is approximately 200 nm thick). Not all components of sunlight (approximately 280-2,800 nm) are useful for plant growth and development. In general, ultraviolet (UV; less than 380 nm) and excessive infrared (IR; above 770 nm) or heat radiation can be harmful to plants and should be avoided. Plants use Photosynthetically Active Radiation (PAR; 400-700 nm), as their energy source for the process of photosynthesis. Therefore, greenhouse structures and especially the glazing material should have a high transmittance of PAR radiation. Note that the terms light and radiation

are used interchangeably and that visible light is not exactly the same as PAR. Visible light (the colors in a rainbow; ROYGBIV) consist of wavelengths that cover a slightly larger part of the radiation spectrum (380-770 nm). Since light is the driving force for photosynthesis, small changes in light intensity have an immediate effect on the rate of photosynthesis. Plants respond to changes in light intensity very rapidly.

Direct and Diffused Radiation

In order to understand the impact of greenhouse glazings on crop production, we have to investigate how light interacts with these cladding materials. Based on physical properties, surface orientation (angle of incidence), and the number of layers of the glazing material, portions of the incoming light are either transmitted, reflected and/or absorbed.

On a cloudless day, most sunlight travels in a straight path through the Earth's atmosphere. Under these conditions, the incoming light is termed direct radiation. On a cloudy day, the sunlight is diffused by the many water vapor particles in the moisture-laden air. This light is called diffuse radiation. It is important to understand that diffuse radiation reaches the greenhouse surface from many different directions other than the direction of its source (the sun). This phenomenon can actually be an advantage for greenhouse crop production. Diffuse light is capable of reaching deeper into the plant canopy because it can penetrate from many different angles. This results in improved plant growth. However, the light intensity from diffuse light is usually much lower than the intensity from direct light.

In addition to the interaction between incoming light and the greenhouse cladding material, structural elements such as posts, trusses and equipment (e.g., overhead heating pipes, shade curtains and supplemental light fixtures) reduce the amount of light that reaches the top of the plant canopy. It is not unusual for a greenhouse structure to reduce the amount of light that ultimately reaches the plant canopy by an average of 40-50 percent compared to the amount of light available outside the greenhouse. Therefore, the need for maximum light transmission should be one of the main criteria during the design of greenhouses and overhead equipment, and in selecting glazing materials.

Types of Glazing Materials

The most common greenhouse glazing materials are glass, rigid plastics and plastic films (Table 1).

Glass

Glass has the highest light transmission, lasts the longest (30-plus years) and is the most expensive. Tempered or laminated glass is recommended because it is stronger allowing for fewer support bars, and it increases the safety for people working underneath in case of breakage (check the local building code). Most glass greenhouses are clad with a single layer resulting in a relatively high heat transfer coefficient (Table 2).

Rigid Plastics

Rigid plastics (e.g., polycarbonate and acrylic) are less expensive than glass and last seven to 20 years. They are usually manufactured as twin-walled sheets. The air space between the two walls acts as an insulator. Light transmission through rigid plastics is very good, although it usually decreases over time as the plastics age and turn yellow due to the amount of UV radiation contained in sunlight. The large sheets are much

lighter than glass and require fewer support bars to attach them to the greenhouse frame. However, these rigid panels are not so easy to install on curved roofs.

Plastic Films

Plastic films (e.g., polyethylene) are the cheapest greenhouse cladding material, but they usually last only three to four years. Plastic films, normally 4-6 mils thick, are almost always installed in two layers that are inflated by a small fan. This provides some strength to the greenhouse surface and the air space between the layers acts as an insulator, significantly reducing the heat loss from the greenhouse. Air-inflated greenhouse surfaces experience approximately 60 percent of the heat loss compared to similar surfaces clad with a single layer of glass or plastic. It is important to always use outside air to inflate the two layers of film because this will significantly reduce potential condensation between the layers. A common additive to the film material (the so-called IR films) helps reduce the heat loss from the greenhouse during cold outside conditions. Some films are manufactured with a special surface treatment to prevent condensation droplets from falling on the crop (so-called no-drip films). Instead, the condensation water channels along the film and runs off to the side.

Table 1. Comparison of characteristics for greenhouse glazing materials.

Cladding material	Transmittance (%)			Life expectancy (years)
	PAR ^z	Infrared ^y	Ultraviolet ^x	
Glass	90	< 3	60-70	30+
Acrylic ^y	86	< 3	44	20
Polycarbonate ^w	75	< 3	18	10
Polyethylene ^v	88	50	80	3-4
PE, IR & AC ^{uv}	88	30	80	3-4

^zPhotosynthetically Active Radiation (400 to 700 nm); Energy source for the process of photosynthesis.

^yInfrared heat transmittance (>3,000 nm)

^xWavelengths (300 to 400 nm)

^wTwin wall

^vSingle layer

^uPolyethylene film with an infrared barrier and an anti-condensate surface treatment

Table 2. Heat-loss coefficients (U-values) for glazing and construction materials.

Cladding material	U (Btu/hour per sq. ft. per °F) = 1/R
Single (double) layer glass	1.1 (0.7)
Single (double) layer polyethylene	1.1 (0.7)
Double layer + energy curtain	0.3-0.5
Twin-wall layer acrylic	0.6
Twin-wall polycarbonate	0.6
1/2-inch plywood	0.7
8-inch concrete block	0.5
2-inch polystyrene board	0.1