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VI - Understanding Light in a Passive Solar Greenhouse

Light is all around us-but it's more complex than it seems. Sometimes it behaves like a wave (energy), and sometimes like a particle (matter). In this chapter, we explore some properties of light as they apply to passive solar design, focusing on how it enters the structure, how it's used by plants, and how we can maximize its benefits.

What Is Incident Solar Radiation?

When sunlight strikes a surface, we refer to it as incident solar radiation or insolation. In passive solar greenhouses, the incoming sunlight is the main source of energy that powers photosynthesis, heats the structure, and helps cool and ventilate the structure. Much of that initial heat is stored in thermal mass inside the greenhouse to be released later as needed at night or on cold cloudy days to keep the greenhouse warm. Eventually, the sun's energy exits as low-grade heat through the walls, glazing, roof, and floor.

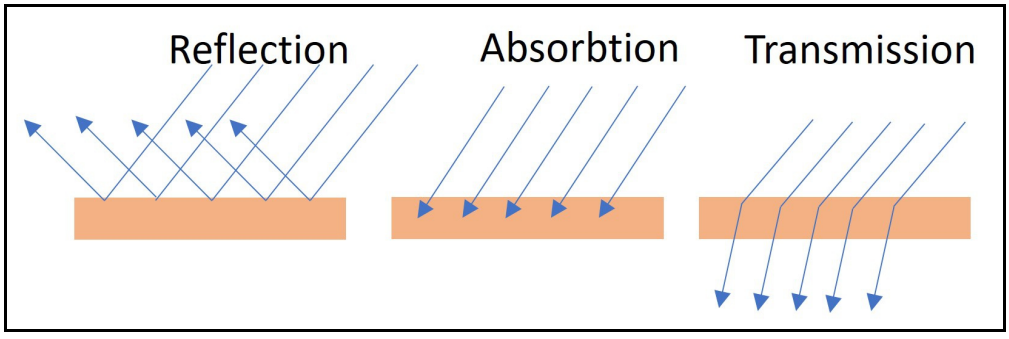
Sunlight enters a greenhouse in three forms:

1. Direct sunlight is the most intense and most useful for heat and photosynthesis; it is the largest percentage of the insolation entering the greenhouse on sunny days.

2. Diffuse sunlight is less intense light scattered from clouds, atmospheric pollution, or tree canopies, and the lower angle of the sun to the horizon in the winter (as it has a longer way to travel through the atmosphere). Diffuse light is softer but still useful.

3. Reflected sunlight is light that bounces off surfaces like snow, lakes and ponds, buildings, or pavement before entering.

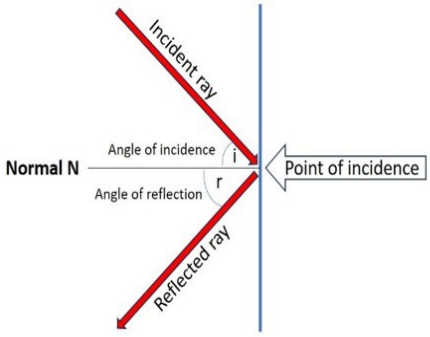
When light strikes a surface, three things can happen: it may be reflected off the surface as various colors of light; it may be absorbed and converted to heat (especially by dark surfaces or thermal mass); or it may be transmitted through the surface (like windows and glazing.



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How Light Reflects

When light reflects off a surface, the incident angle (incoming) and reflected angle (outgoing) are equal relative to an imaginary line perpendicular to the surface of an object at the point where the light strikes the surface. This imaginary line is called the normal. This matters when designing your glazing: the more perpendicular the sun is to the surface of the glazing, the more light gets through. As the sun hits the glazing at lower angles or more sideways, less light is transmitted and more is reflected. Transmission starts to drop off quickly at incident angles greater than 40-50°: ~87% at 30° incident angle, but dropping to ~71% at 45°. This can be seen in the light bouncing off the glazing of the modified gothic-style hoophouse at the SD Farm in Valle Crucis and the rather shady conditions of the interior even under bright blue sky – the angles of its south-facing glazing are not designed for solar gain.



Laws of reflection
1. The incident ray, the reflected ray, and the normal all lie on the same place.
2. The angle of incidence (i) is always equal to the angle of reflection (r).



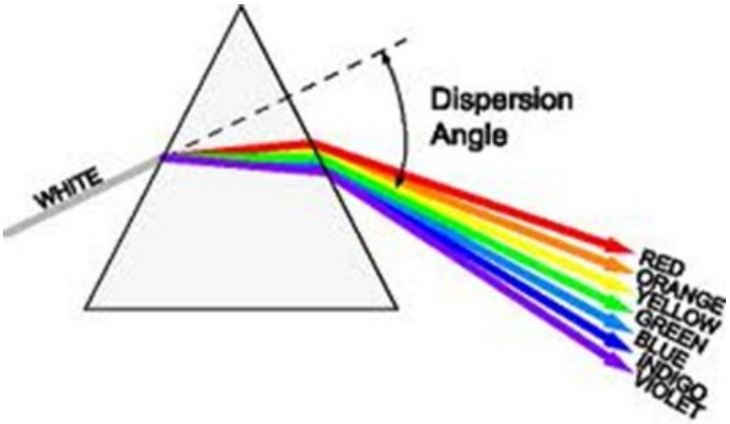
Photo: den Biggelaar, November 2006.

The Light Spectrum

Natural sunlight is made up by a spectrum of many different wavelengths or frequencies, ranging from 1 to 1,000,000 nanometers (nm):

- Ultraviolet (UV): under 390 nm.
- Visible light: 390-760 nm; it represents the violet through red colors of a rainbow.
- Photosynthetically Active Radiation (PAR): 400-760 nm (most useful to plants).
- Infrared (IR): over 760 nm is felt as heat, especially above 3000 nm.

Ultraviolet and infrared are invisible to the human eye, but can be seen by other organisms. A prism or water droplets can separate white light into its component parts, which we can observe as rainbows.

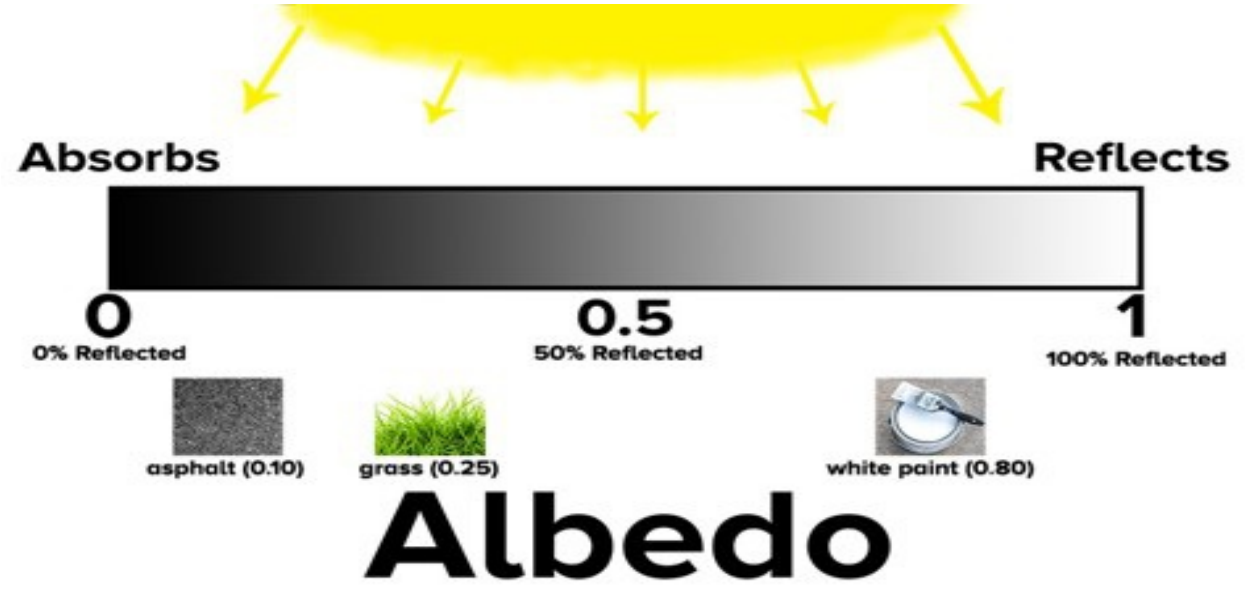


Our eyes perceive different wavelengths of visible light as color. White light includes all colors of a rainbow; but when you see a color – like red – it is part of the spectrum being reflected, while the other colors are absorbed or transmitted. The same is true for green, blue and the other colors. It is

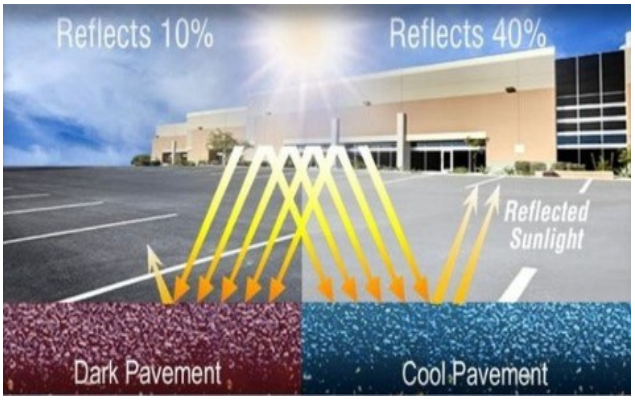
important to note that an object can only reflect or transmit colors that are present in the light striking the object. If only blue light is striking a red object, the object will appear black since there is no red light to reflect.

- White objects reflect nearly all visible wavelengths.
- Black objects absorb most visible light and convert it to heat.
- A red object reflects red light but absorbs other colors.

How much sunlight is reflected by a surface is measured by its albedo, expressed as a fraction from 0 (no reflection) to 1 (total reflection). Surfaces with high albedo, like snow, reflect most sunlight, while darker surfaces, like asphalt, absorb more light and heat.



For example: black asphalt pavement on a bright sunny day feels hotter as it absorbs as much as 90% of the light, whereas a grey concrete road stays cooler as it reflects up to 40% of sunlight.



Light and thermal mass

Thermal mass functions best with a flat black color, but flat red and flat blue are also useful colors for optimizing thermal storage and possibly reflecting extra light most useful for plant growth back on the plants. Items without much thermal mass such as walls and ceiling can be painted light colors to keep them from absorbing a lot of heat, instead reflecting that high quality sunlight back to plants and useful thermal mass. Table VI.1 lists the reflectivity of different materials and paints.

Table VI.1. Reflectivity of different materials and paints.

Snow	90%	Red brickwork	45%
Aluminum foil	88%	Concrete	40%
Gloss white paint	80%	Red paint	24%
White paper	75%	Brown quarry tiles	20%
Flat white paint	70%	Gloss black paint	9%
Buff brick work	60%	Flat black paint	2%
Aluminum paint	55%		

Light and Plant Growth

Many plants do not use as much of the green wavelengths of light as they do reds and blues; most plants reflect some of the green light that strikes their leaves making them appear green! The different shades of green of plants' leaves are due to the slightly different amounts of red and blue being absorbed or reflected. But modern research shows plants do use green light – just not as efficiently as red and blue (see Erik Runkle reference at the end of the chapter). Full spectrum LEDs, which include all colors, may be better for plant growth than red/blue-only LED lighting.

Glazing Angle: Controlling Light and Heat

Sunlight intensity (i.e., its quality and quantity) varies widely from one area to another due to differences in day length caused by the seasons, latitude and altitude, topography, weather and air quality. To increase the amount of solar radiation entering a PSG, the aperture (the south-facing glazing area) can be enlarged to allow more sunlight in. This can be done by increasing the roof (north) angle.

One factor that, in part, determines the amount of sunlight entering the structure is the angle of the glazing to the incoming sun rays. This impacts the amount of sunlight entering the greenhouse in two ways:

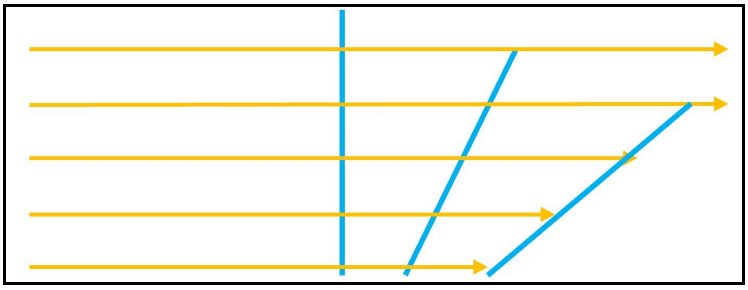


Figure VI.1. The amount of sunlight entering the greenhouse decreases as the glazing is laid back more.

1. Insolation decreases as the glazing is tilted away from perpendicular to the light source (more parallel to the light) (Figure VI.1). Even though the glazing area (ft^2 or m^2) may be the same, the *effective glazing area* is less as it is more perpendicular to the incoming insolation.

2. Only slightly at first, then generally somewhere around 40-50^0 incident angle, light transmission drops off fast and light reflection increases (Figure VI.2). A good analogy is the skipping of a rock on water – it works best when thrown nearly parallel to the surface – just like summer sunlight bouncing off shallow-angled glazing. But throwing the rock down sharply, it sinks. That's winter sun – low on the horizon, entering almost perpendicular to the surface of the 60^0 angled glazing.

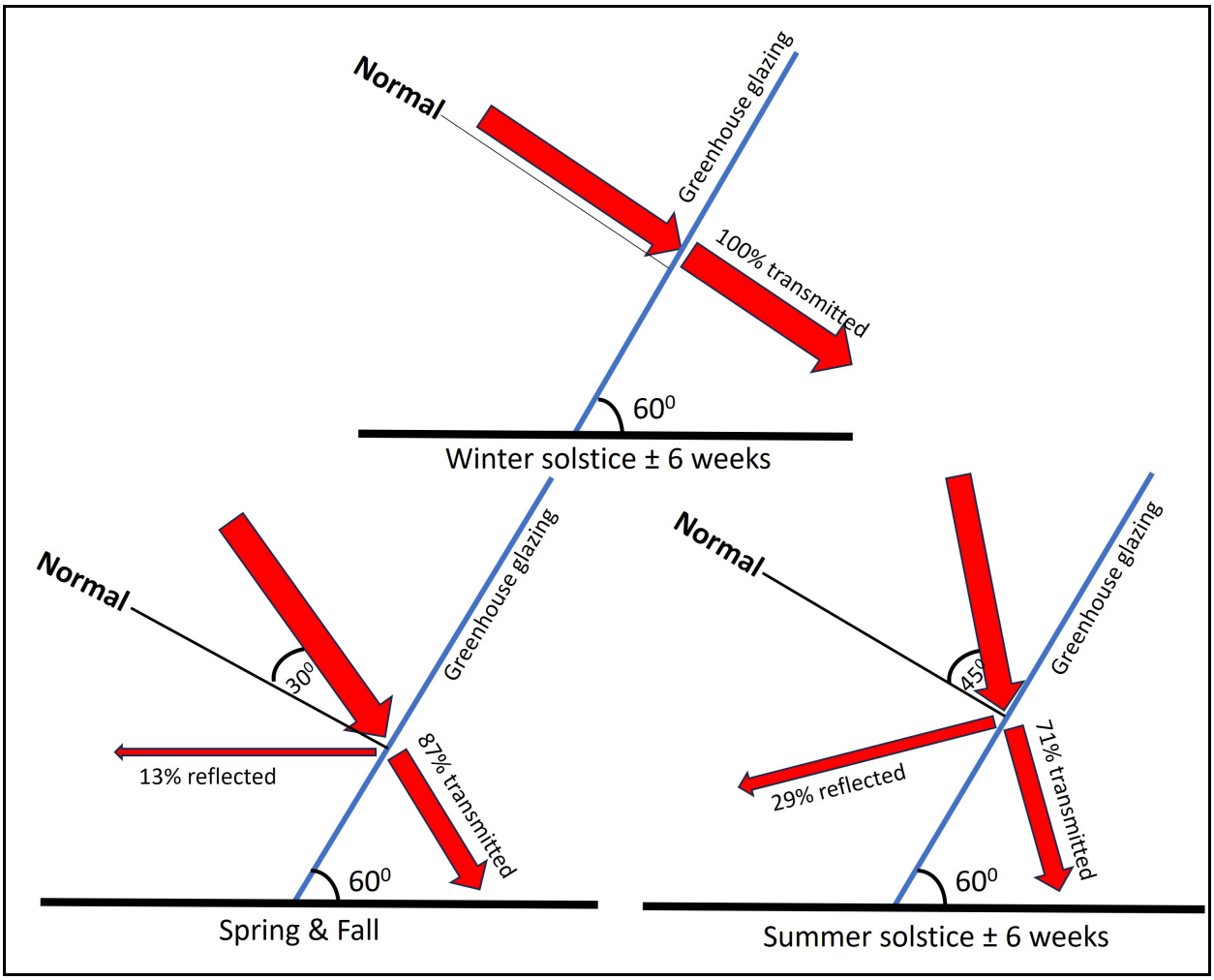


Figure VI.2. Most of the light striking the glazing perpendicularly is transmitted, but more of the light striking the glazing at an angle will reflect in proportion to that angle.

SunCatchers are designed to regulate solar input by seasonal changing angle of the glazing relative to the angle of the sun (Figure VI.1). To capture low-angle winter light, the SunCatcher's glazing is tilted 60° from horizontal. This helps nearly 100% of sunlight to penetrate the structure when it's most needed (winter period). At 36^0 latitude, as the sun gets higher in the sky in spring, the angle of incidence striking the glazing is about 30^0; at this angle 87% of light is transmitted while 13% is reflected. At the even higher angle around the summer solstice, only 71% of light is transmitted with 29% reflected off the glazing, reducing overheating. Additional shade cloths can help reduce overheating in Spring and Fall.

The amount of sunlight being transmitted is also determined by the effective cross-sectional area of the glazing (which decreases as glazing tilts away from the sun) as well as glazing area being taken away by its framing and rafters supporting it. For the 32 x 16 ft Hawk's Nest SunCatcher, framing and rafters decrease the effective glazing area by about 13%.

Designing for Light Reflection Inside

To maximize the use of sunlight coming into the greenhouse before that energy is lost as waste heat through exterior surfaces, we suggest that all interior walls be a light reflective color, preferably gloss white, to reflect maximum incoming sunlight in the winter months toward the growing space and thermal mass (more on this in Chapter XIV). This increases the amount of natural light reaching the plants compared to the amount of light that same foot print outside of the structure would normally receive during the winter months. This increases overall usable light and helps reduce phototropism (plants growing toward light sources).

Key Light Concepts for PSGs

1. Sunlight comes in direct, diffuse, and reflected forms
2. Light can be transmitted, reflected, or absorbed
3. The angle and effective area of glazing impacts how much light can enter the structure
4. Light color impacts plant use and heat gain
5. Glazing and internal surface colors effect heat retention and light distribution

By understanding and applying these concepts, you can maximize the benefits of sunlight in a passive solar greenhouse-reducing energy use and increasing plant productivity.

Further reading

Erik Runkle: Growing plants with green light

ExciteLED.eu: The Absorption and Action Spectrum in Photosynthesis

Clegg & Watkins, Fig. 11.6 Reflectivity Chart, p. 180.

Hewitt, Conceptual Physics (on wave/particle behavior)

Mazria, Light characteristics. In: The Passive Solar Energy Book, pp. 5-20.

U.S. Department of Energy: Energy-Efficient Window Coverings