W 935-B

SELECTING AND DESIGNING SMALL-SCALE GREENHOUSES TO FIT YOUR NEEDS

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Greenhouses enable the environment around plants to be altered to optimize growth and quality, and they can even enable year-round growing with proper equipment and management. The cultivation of plants in small-scale greenhouses for personal or instructional use has many enjoyable aspects beyond food production or plant growth. From learning and teaching new skills to quality of life benefits, greenhouses can be a valuable asset to a range of horticulture and gardening pursuits. This publication is the second in the **W 935 publication series** that will cover some of the most common benefits and uses as well as design and management aspects of small-scale greenhouses for residential or educational use in Tennessee.

INTRODUCTION: GREENHOUSES ARE TOOLS TO ALTER PLANT ENVIRONMENTS

Greenhouses are structures that alter the environment around crops and provide conditions that optimize plant growth and/or quality. Greenhouse frames are enclosed with transparent coverings that can be plastic or glass. The transparency of these materials allows solar radiation to pass through and provide light for photosynthesis as well as heat. However, this requirement of letting light pass through means that greenhouse coverings have low heat retention (low insulation properties) as compared to other buildings, so consistent heating will be needed to maintain temperatures across most of the fall to early spring months. Our use of the term greenhouse will refer to structures that use both passive and active environmental control. Greenhouses use passive heating from sunlight, but also include active environmental control for heating, cooling, supplemental light, humidity and even carbon dioxide. It is more common to refer to plastic covered structures without heating as high tunnels (Figure 1), which are covered in UT Extension publication **W 346-F**. This discussion will be focused on small-scale residential or educational greenhouses that include some type of heating (and possibly cooling) system while generally relying on natural light. This combination of growing environment management in greenhouses is the most common for homeowner and most educational uses.

PLANNING THE SMALL-SCALE GREENHOUSE

Greenhouse plans should consider current and possible future uses and be a value to the property rather than a detraction. Confirming that greenhouse structures are allowed at the site is a crucial early step. Homeowners association guidelines or other municipal regulations, such as building codes, should be consulted. It is also wise to discuss insurance options with carriers before construction begins.

FIGURE 1. *This is the inside of a hoop (or Quonset) style structure with polycarbonate covering. While this design would work well in the spring and fall seasons, the doors are the main method of ventilation and there are no heaters or cooling pads. Since this structure is more a high tunnel than a greenhouse, there would be limits to the growing season in this structure. Image: Shutterstock*

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Site selection plays a key role in the construction and long-term productivity of the greenhouse structure. Access to the site is important during construction as is the proximity of water and gas (or other heating fuels). Even near a residence, school or other existing structure, there can be costs or hurdles in terms of bringing gas or electric service to the greenhouse.

Many of the same considerations apply to access to an adequate and high-quality water source. Well water is the most cost effective if available, but municipal sources can also be used. Keep in mind that water sources should be tested prior to beginning construction because poor quality water (high salts or sulfur, iron or manganese, for instance) could add expense and complications even for small growers. Water that has been treated with a softener is not generally useable due to the high salt content. Surface waters (creeks, ponds) are much less commonly used due to concerns about contamination, consistency, pumping systems and the likelihood that treatment will be required. Some small-scale greenhouse users will prefer to use captured water, such as that from rain barrels, but beware of the potential for contamination, which can be a greater risk in greenhouses with soilless growing mediums than it might be outdoors when added to soil. Additionally, captured water is likely to be less consistent in volume than is typically needed for greenhouse growing.

In all cases, siting should avoid shading from nearby trees or buildings to maximize sunlight in the times of year when plants are most likely to be growing in the greenhouse. A distance of at least 2.5 times the height of shading objects (buildings, trees)

Figure 2. *This small greenhouse is peaked to better shed winter precipitation and has straps added to better withstand winds. Image: Shutterstock*

is a good rule of thumb. Also keep in mind that shadows are longer in the winter, which could be an issue for early transplant growing or year-round foliage or flowering plants.

Building a greenhouse on a slope can create construction issues. Also make sure that greenhouses aren't built in low-lying areas where water may pool during precipitation events. Many sites can be graded to provide a level (or nearly level) site for greenhouse construction or ensure water is diverted, but these steps can add significant costs.

Directional orientation is usually based on sunlight patterns and prevailing winds as well as season of use. In northern locations (above 40 degrees north latitude) that require winter or early spring production, light can often be limiting, so some prefer an east/west orientation that allows winter light to enter the side of the greenhouse rather than the end. In more southern areas, north/south orientation can reduce shadows in the greenhouse over the course of the whole year. For residential and many educational greenhouses, there may be few choices in terms of orientation, so air movement and wind direction may take precedence.

It is best to orient the greenhouse so that exhaust fans work in tandem with prevailing winds instead of forcing the fans to blow against incoming wind. In high wind areas, greenhouses may be constructed parallel to prevailing winds to lower wind loads on the structure created by wind hitting the broad side of the greenhouse.

GREENHOUSE DESIGN AND CONSTRUCTION

STRUCTURAL DESIGNS

Since the range of crops and seasons vary, there is no one correct greenhouse design or size. Most small greenhouses are designed to provide 70-80% of the square footage in bench or useable floor space for growing. So, this can be a useful calculation when determining how much space is needed. Generally, 100 square feet is considered a minimum for utility and cost efficiency. If less space than this is needed, a window greenhouse or cold frame may be an option.

The size of the greenhouse is also directly related to the speed of heat gain and loss. Temperature control can be harder to maintain in small greenhouses because of rapid changes in the small air space. So, homeowners should consider the seasons when the greenhouse will be needed and the ability to control temperatures in that space. If primarily used in winter and spring, smaller sizes may be possible because heating costs will be smaller and heat gain from sunlight will be less of a factor. But for more year-round use, larger greenhouses will moderate the temperature better to manage later spring, summer and fall temperature gains due to sunlight.

A-frame, lean-to, partially in-ground (Figure 3), and hoop or Quonset structures are common options for residential greenhouses (Figure 1). One of the main differences in these structures is whether they are free-standing or connected to the house or another structure such as a garage. Connecting a small greenhouse can reduce costs and enable easier access to fuel sources, electricity and water. It can also potentially reduce light or create challenges in some areas where structures are tightly regulated. Homeowners should carefully consider these potential benefits and constraints. While designing and building a greenhouse yourself is an option, most home greenhouses are purchased as a kit. So, selection of materials and the key attributes to look for in greenhouse kits will be the focus of this planning section.

While production greenhouses are carefully designed to meet specific engineering guidelines in regards to wind and snow loads, there are fewer restrictions on small, non-commercial greenhouses. Keep in mind that when it comes to withstanding snow most greenhouses are designed so that the heat within the structure melts snowfall. So, leaving small greenhouses unheated in the winter can be risky if heavy snow is expected. Peaked structures can be better at shedding both snow and potentially ice, which is likely to be more of a damage risk in Tennessee than heavy snow loads (Figure 2).

GREENHOUSE TERMINOLOGY

Photosynthetically active radiation (PAR)

light wavelengths between 400 and 700 nanometers that is most valuable for plant use

Polycarbonate (PC)

a rigid plastic material (often corrugated) used for greenhouse covering

Polyethylene (PE)

a soft, flexible plastic used for greenhouse covering

GREENHOUSE TERMINOLOGY CONT.

Passive control

using only ambient solar radiation and natural air movement to manage the greenhouse environment

Active control

using heaters, fans and other tools to manage the greenhouse environment

Daily light integral (DLI)

sum of PAR light in a given area over an entire day

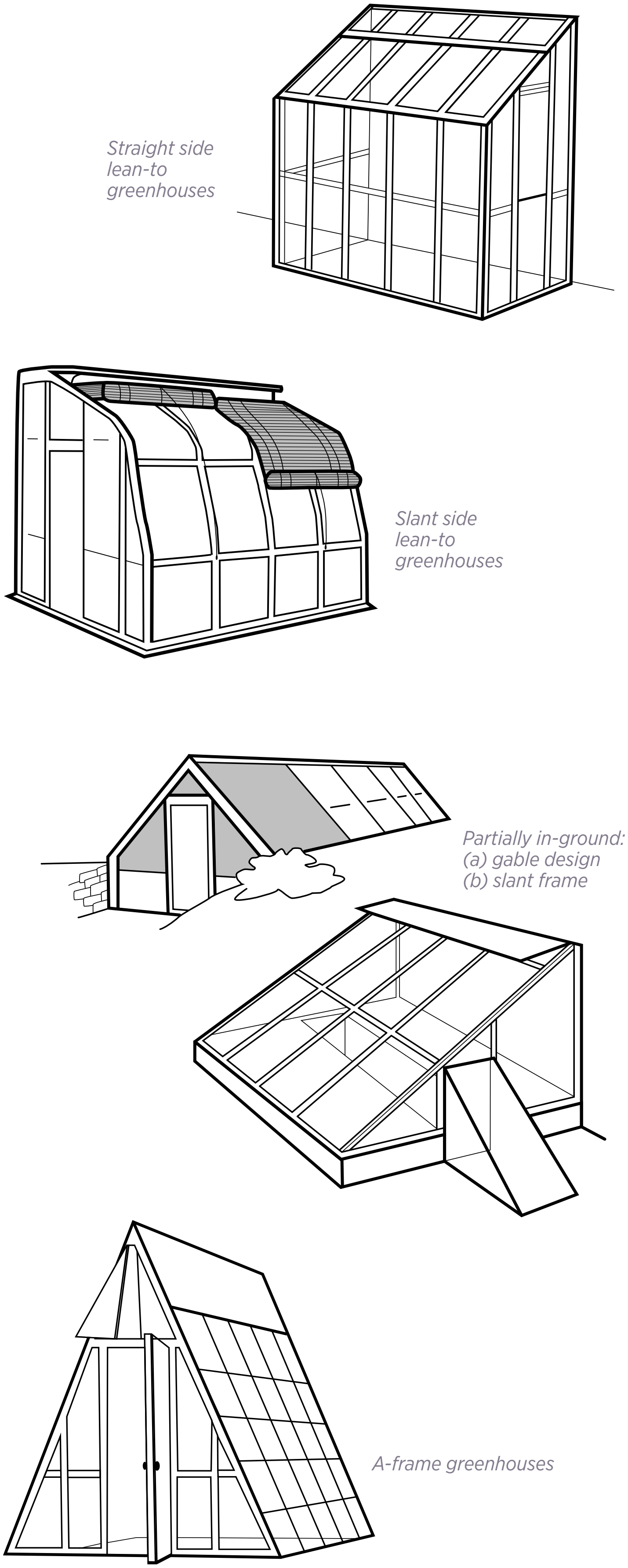

FIGURE 3. Examples of different designs for small greenhouses

Likewise, consider the design of the greenhouse and how well it may withstand strong winds. Wind resistance relies on the strength of the framing materials, but also the strength of the connection to the ground and the tightness of the greenhouse. Often wind damage occurs when air quickly enters the greenhouse, so tight vents, doors and connections to the ground are important to exclude wind and keep the structure from being damaged.

A final consideration in greenhouse structures is their ability to support crop loads in the house. If you need to support hanging baskets, tall tomato plants or other weight inside the house, make sure to discuss this need with the greenhouse manufacturer.

FRAMING

Wood, steel and aluminum are all materials for greenhouse construction. Wood and/or steel are most typically used as the frame, which includes posts, beams, arches and trusses. However, wood may need to be treated to prevent decay and degradation. Often the skeleton of the greenhouse will come in a kit or pre-welded parts, so galvanized steel structures dominate the greenhouse industry. Smaller houses often are constructed with aluminum instead of steel to reduce costs (see Figure 2).

FLOORING

There are several flooring options to consider, with the two most common being concrete and gravel. Concrete is a firm surface to work on and can be cleaned easily and even painted to absorb heat or reflect light. Another possibility is porous concrete, a specially aggregated cement that provides solid flooring while still allowing drainage. It can eliminate standing water, which can harbor pathogens and pests. However, porous concrete can be a challenge in areas with a high volume of loose particles (perlite, peat, vermiculite), which can clog the pores.

Gravel can be an advantage due to lower cost and its ability to drain water well. However, it is harder to clean, keep free from weeds and can be a challenge for some greenhouse equipment,

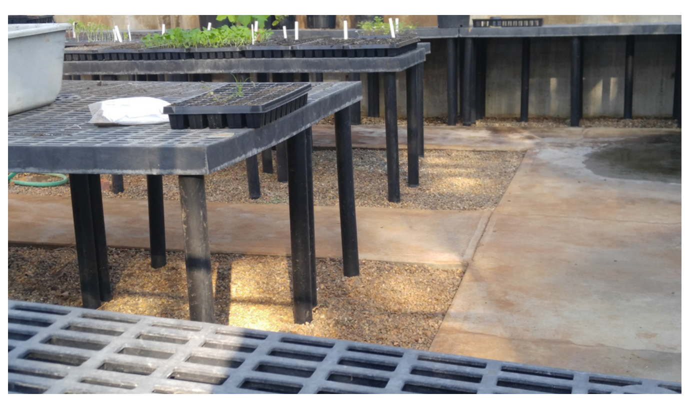

FIGURE 4. A small greenhouse with concrete walkways and gravel under the benches to support drainage.

such as carts and buggies, to move across smoothly. Many greenhouses have gravel floors with concrete aisles to provide drainage, some weed control and easier maneuverability (Figure 4).

GREENHOUSES AND LIGHT

A brief overview of light and energy connections in the greenhouse will help in selecting covering materials. Light is a critical factor in plant growth and is often one of the most limiting resources in off-season use of greenhouses. Because of these light concerns, the design and outer clear covering (sometimes also called skin or glazing) of the greenhouse is often selected to optimize light penetration. While solar radiation is technically “free,” there are many costs associated with harvesting light. This includes the cost of building the greenhouse structure and the heating or cooling expense of maintaining an environment under a clear covering.

Light, quite simply, is energy in the form of electromagnetic radiation. Such energy can come from lamps or artificial lights in a greenhouse or the sun. Whatever the source, light energy can be described in terms of quality, quantity and duration.

Quality describes the wavelength of light and corresponds to the energy that occurs across a spectrum. Shorter wavelengths have higher energy than longer wavelengths, and the units we use to describe wavelengths are nanometers. One nanometer is a billionth of a meter. Ultraviolet light is in this short wavelength category and includes 100-380 nm wavelengths. UV light has enough energy that it can be damaging to plants, humans and greenhouse plastics. Plants can synthesize compounds to protect their photosynthetic systems from this high energy light while greenhouse plastics have materials in them to protect against UV light breakdown. Even with these materials, damage and aging of plastics occurs and is the main reason that plastic covering needs to be replaced every few years (often three to five).

Visible light is in the 380-770 nm range while plants utilize light between 400 and 700 nm for photosynthesis, called photosynthetically active radiation (PAR). Wavelengths higher than 700 nm are still important for plants and impact many developmental aspects, such as germination and flower induction. Long wavelength light is also responsible for providing heat in greenhouses. In fact, one of the main sources of this long wavelength radiation is light that is absorbed and then reradiated from plants or light that is transmitted through the greenhouse

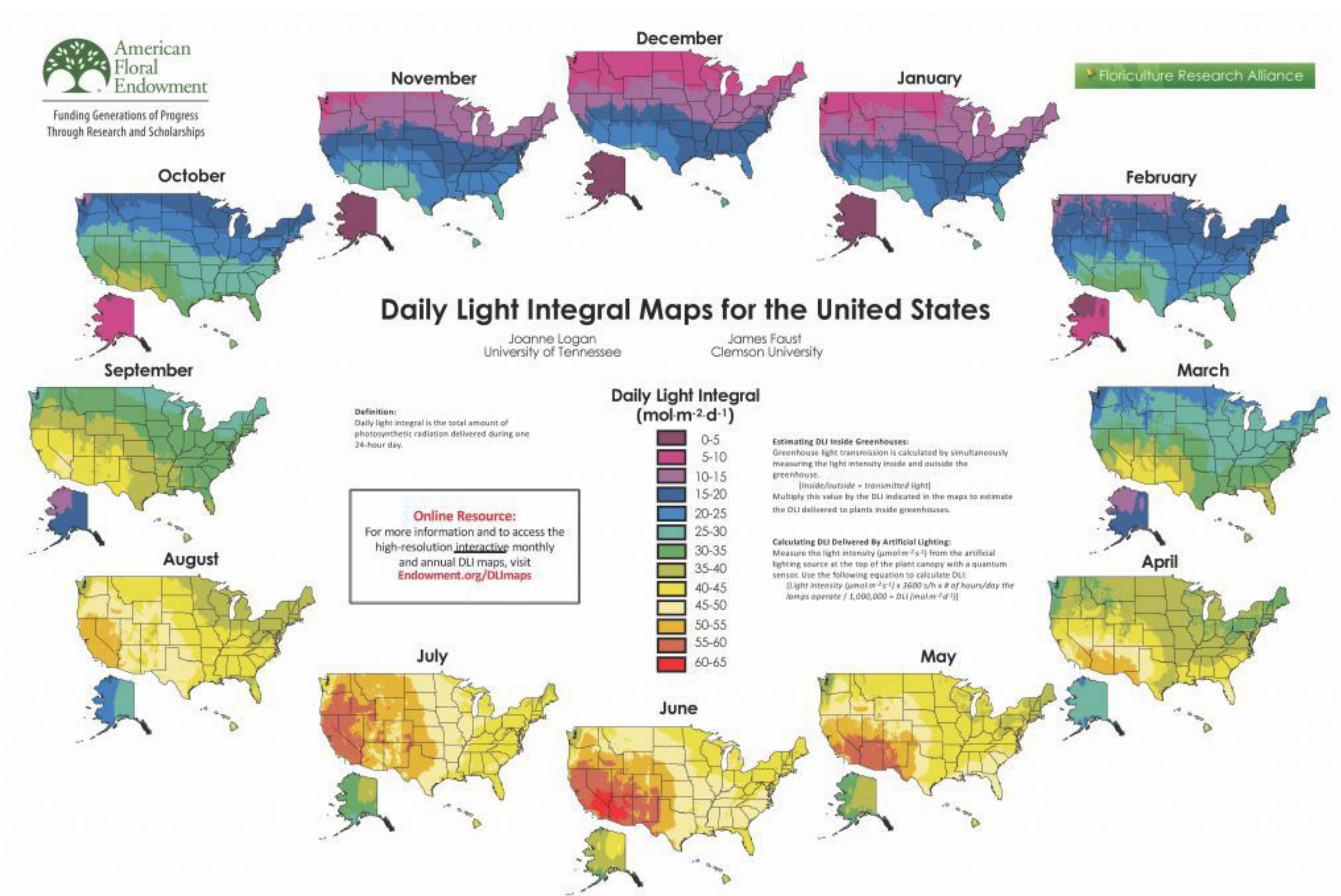

FIGURE 5. Daily light integral map of the US at different times of year. Image credits: Clemson University and University of Tennessee

plastic and is then reflected back within the structure. Whether in a greenhouse or the earth's atmosphere, this phenomenon is called the greenhouse effect.

Intensity of light is the quantity of a given wavelength per unit area per unit of time. There are several terms used to describe light intensity. Engineers often use the term watts per meter squared (W/m^2), while horticulturists often use the term micromoles of photons per meter squared per second ($\mu mol/m^2/sec$). This horticultural term usually describes only PAR light, while W/m^2 describes light across a wider spectrum. Foot-candle describes light perceived by human eyes, and while it is a common term for photographers and others, it is not the most useful measure in talking about light and plant growth in greenhouses.

Duration of light is a term that is related to accumulation. Light duration can influence plant development due to photoperiod effects. For many non-flowering crops, photoperiod is not the primary concern, and it is more important for growers to understand accumulated light because of the impact on photosynthesis and plant growth and yield over time. A simple analogy is to think of light intensity as rain drops and light accumulation as inches in a rain gauge. Plant scientists describe the light in the "rain gauge" as daily light integral (DLI), which is $mol/m^2/day$. It is this term that will be used to present general light needs of greenhouse crops as well as light that is available on average at that location during that time of year (Figure 5).

How are these light values useful? Well, let's start with crop needs. Most growers would prefer to have 10-12 $mol/m^2/day$ to produce a high quality transplant in the spring, while 15-17 $mol/m^2/day$ is best for a head of lettuce in a greenhouse. Producing high quality greenhouse fruiting crops, like tomatoes and cucumbers requires even more light, with 20 $mol/m^2/day$ being a good target. These values can be used to determine how successful the growing of specific crops could be in different locations at different times of year using the information in Figure 5. Figure 5 provides outdoor values, so adjustments should be made for the light blocked by the greenhouse itself. If you don't have access to a light meter, than a reasonable greenhouse estimate would be 2/3 of the outdoor light. This would mean that the 25-30 $mol/m^2/day$ outdoor light in March in Tennessee (Figure 5) could provide 17-20 $mol/m^2/day$ in many greenhouses, which would support growth of most crops. However, the 10-15 $mol/m^2/day$ available outdoors in Tennessee in December (Figure 5) would only provide around 7-10 $mol/m^2/day$ in a typical greenhouse, which would not support the ideal growth of most bedding plants or vegetables. Low light levels at this time period could cause plants to stretch, time to harvest to be increased or lead to flowering plants with low visual quality.

GREENHOUSE COVERINGS

Prior to the mid-1900's, greenhouses were constructed with wood, iron or steel and covered with glass. The price and labor involved in building and maintaining such structures limited their use. In recent decades, a wider array of lighter, stronger and more cost effective plastic coverings have become available.

There are several types of plastic coverings, the most common of which are polyethylene (PE) and polycarbonate (PC). In addition to lower cost, these plastic coverings often have lower heat loss due to the continuous sheet covering which lowers air loss and winter energy costs versus many panes of a single layer of glass. Glass, though, is a very high quality covering that is still used. The air movement and heat loss between panes of glass can reduce humidity and disease potential in the greenhouse. Glass materials have improved in safety, durability and ease of installation over the years and last longer than many plastic materials. And, in terms of light transmission, glass is still the best greenhouse covering.

Table 1. *Comparison of common covering material attributes*

	*Light transmission**†	*Suitability for hail/ice*	*Heat loss in Btu (U value)* †
Single layer glass	90-92%	Reasonable	1.13
Double layer glass	81-85%	Reasonable	0.70
Single layer polyethylene	87%	Poor	1.20
Double layer polyethylene	76%	Poor	0.70
8 mm polycarbonate	79%	Reasonable	0.65
16 mm polycarbonate	77%	Reasonable	0.58
Acrylic 8 mm (2 layer)	83%	Reasonable	0.58-0.65
Corrugated Fiber Reinforced Plastic	88%	Reasonable	1.20

**light transmission is PAR values from American Society of Agricultural Engineers- 1995*
†reported in Greenhouse Operation and Management Edition 6

Figure 6. This plastic covered quonset greenhouse has a heating tube that distributes warm air down the length of the greenhouse.

Polyethylene (PE) Films

PE films are currently one of the most popular glazing materials in the industry (Figure 6). PE balances low cost with good light transmittance. Often two layers of PE are used and a small fan provides air to inflate the space between the films. This double layer provides insulation (created by the dead air space between the film) to reduce the speed of heat gain and loss. This double layer can also extend the life of the film, but it does reduce light transmission. The balance between light entering and heat escaping is one of the central challenges in greenhouse design and management.

Most greenhouses today use a film that is 6 mil thick to provide 4 or more years of usefulness. Some operations, such as nurseries, might use a 3 or 4 mil plastic that is taken off after a single season. Chemical inhibitors are added to prevent UV light from degrading the film to increase the life span of the film, and certain inhibitors can be added to reduce wavelengths that are not used in photosynthesis. Infrared blocking (longer wave radiation) PE materials are available, which lowers the rate of heat loss to clear skies (usually at night). It can also reduce the rate of heat gain with daytime high light conditions. Some greenhouse covering materials have anti-condensate or anti-drip properties to encourage water to run down the inner slope of the roof rather than remain on the plastic to reduce light transmission or drip on the crop below. These properties are particularly useful in PE houses that trap more humidity. However, these properties may not last the entire life of the film. Coating materials are available and can be applied to the inside of the house to reintroduce these properties.

Even with these advancements in PE quality, a key disadvantage to PE is the shorter lifespan compared to glass or rigid plastic. Lifespan is related to the physical durability of the plastic, but also to the light transmission. It is common for greenhouse owners to continue to use plastic if it is physically sound without understanding that light transmission (especially in winter seasons) is being reduced as PE ages. So, it is important to be aware of not only the physical soundness of the cover but also the light transmission. PE films also have some added risk due to hail, ice or other threats to their physical strength.

Rigid Plastics

Rigid plastic alternatives to PE include fiberglass, acrylic and polycarbonate. Fiberglass was a common and relatively low cost material for many years. Composed of translucent rigid corrugated panels that diffuse light, the life span ranged from 8-10 years. The negative aspect of fiberglass is that it only allows a 55-87% light transmittance and this value declines with age

Figure 7. Fiberglass reinforced plastic greenhouse material that has degraded in a way that greatly reduces light transmission.

and degradation by UV light (Figure 7). Acrylic materials have a life span of approximately twenty years and an 85% light transmittance. However, acrylic can be expensive and difficult to find. Polycarbonate is currently the most widely used rigid plastic material due to good light transmittance, insulation quality and added UV inhibitors that provide a twenty year or more life span. Different thicknesses of PC can provide a range of insulation properties as well. Another benefit of these rigid materials is that they provide more protection in climates that are prone to hail and other strong weather events. Those planning to build a greenhouse should consider the following to help guide selection of covering materials:

- What is the light transmission?
- What is the insulation value (heat loss)?
- Does it have a UV inhibitor?
- Does it have infrared blocking?
- What are the purchase, installation and maintenance costs?

GREENHOUSE ENVIRONMENTAL MANAGEMENT

HEATING

Providing proper temperatures in a greenhouse requires growers to balance an understanding of the climate, crop and economics with the design and management of their greenhouse structure. A British thermal unit (Btu) is a common energy term that describes the amount of heat required to raise the temperature of one pound of water by 1 degree Fahrenheit. The unit often used to describe heat loss is the U value, a standard coefficient value that quantifies the ability of the material to transfer heat. The lower the U value the easier it will be to heat the greenhouse (Table 1).

The most common heating systems for small-scale greenhouses are unit heaters because of the low initial cost and the flexibility of installation. Unit heaters are self-contained units that can use natural gas, propane or electric. All fuel heaters used in a greenhouse should burn cleanly and not emit byproducts of incomplete combustion, such as ethylene. Ethylene is a plant growth regulator involved in ripening and aging in plants tissues and can lead to issues in crop production. While natural gas and propane are common in commercial greenhouses, electric can often be the most accessible option for residential greenhouses. In addition to heat sources, heat distribution is essential in the greenhouse. Heating must be combined with well-designed air movement systems to provide even heat distribution throughout the greenhouse. Older systems often used a plastic tube along the length of the greenhouse (Figure 6), but it is much more common now to have horizontal air flow fans to provide consistent heating throughout the greenhouse (Figure 8).

VENTILATION AND COOLING

Proper air circulation and humidity management are all focused on the needs of the plant. Humidity impacts water and nutrient movement through the plant, a process called transpiration, while air movement is essential to provide adequate oxygen and carbon dioxide for photosynthesis. There are also many potential impacts of air movement and humidity on disease risk in the greenhouse. Warmer greenhouse air can hold more moisture than cooler air. So, moisture in the air can condense on the cooler surfaces of the covering and cause dripping or block light. Humidity in the air can be created by irrigation and water vapor released by the plants during photosynthesis. Humidity is managed by ventilation, which exchanges outside air with inside air.

Figure 8. A circulation fan that can be used to mix warm and cool air and maintain even humidity throughout the greenhouse.

There are two approaches to ventilation—a passive system or an active system. Passive means the movement of wind and differences in warm and cold air provides the movement of air through the house. Specially designed openings, such as roof vents, side flaps, roll up curtains or a roof that opens and side wall vents provide the means to pull air from outside through the house. Openings on the roof combined with vents on the sidewalls can create a chimney effect as hot air rises and exits through the roof vent (Figure 9) and cooler air is pulled in the side vents. Orientation and location are all important in driving the flow of air through the greenhouse. In many moderate climates, passively ventilated houses are common. For instance, it might be quite feasible in parts of the northern United States or Europe to have passive (or naturally) cooled greenhouses. However, there are many warmer regions where these houses may not perform well for much of the year.

Active (or forced air) ventilation is the most common system in the middle and southern United States and includes exhaust fans, circulation fans and inlet vents. In fall, winter and early spring conditions, a small fan and vent system near the top of the greenhouse can be used to bring in outside air. This air is often richer in carbon dioxide and lower in humidity than the greenhouse air. These fans can bring in smaller amounts of air that can be mixed and brought up to the temperature of current greenhouse air to prevent large differences in temperature and humidity that could damage crops. They can also reduce greenhouse temperatures on bright days by removing hot air that rises to the tops of greenhouses. During cold weather, cooler air brought in to provide carbon dioxide or reduce humidity must be balanced with the energy expense of heating that air to bring it to adequate temperatures for plant growth.

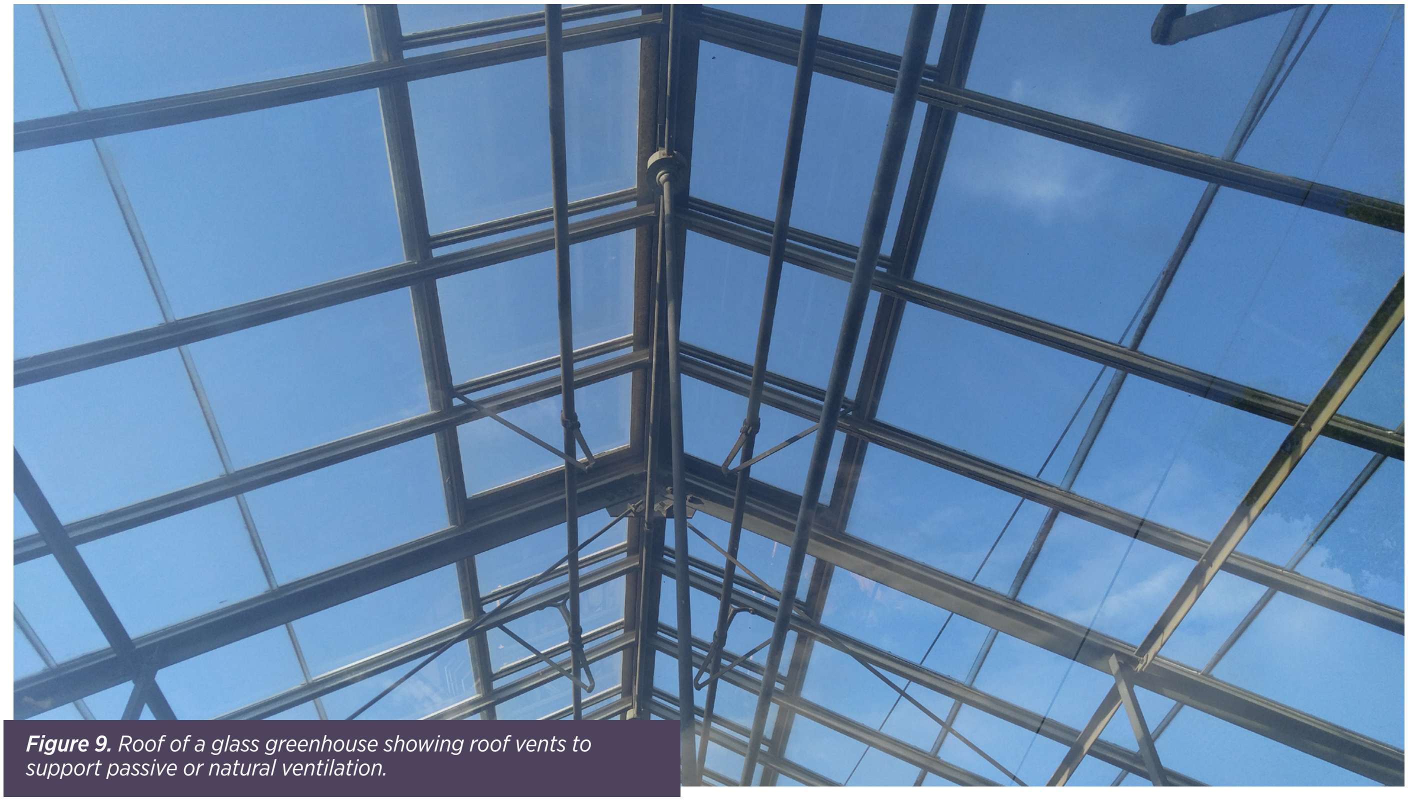

Figure 9. *Roof of a glass greenhouse showing roof vents to support passive or natural ventilation.*

As sunlight and temperatures increase in spring and summer, small fans cannot maintain proper temperatures and greater investments in cooling are needed. Larger exhaust fans are sized to fit the greenhouse and crop. Fan sizing is based on the ability to exchange the air in the greenhouse (Figure 10). It is a common recommendation that an exhaust fan be able to exchange the air in a greenhouse once every minute. So, a greenhouse that is 12 feet by 18 feet by 8 feet should have an exhaust fan that could move 1,728 cubic feet of air per minute (CFM). Exhaust fans can have multiple speeds to enable a range of air movement and cooling for different houses and seasons. So, this maximum CFM could be the high speed of the fan used in summer cooling with a slower setting for spring and fall seasons.

Most active greenhouse cooling systems rely on some form of evaporative cooling. Heat in the air (energy) is used to change liquid water to vapor resulting in a lowered temperature. In all evaporative systems, the ambient humidity restricts the amount of cooling possible because warm, humid air cannot absorb much more moisture to accomplish cooling. There are times when little evaporative cooling is possible in warm, humid climates.

There are a range of evaporative cooling systems including fan and pad, mist and fog, but they all function to evaporate water in warm air to cool it. Fog and mist systems distribute fine droplets of water into the air. These droplets must be fine enough to evaporate rather than settling on benches or plants. Such evaporation lowers the air temperature in the greenhouse while adding humidity. These systems can also be used to adjust humidity when air is drier in the winter or in climates where humidity is naturally low.

Many greenhouses use a system that consists of pads of corrugated cellulose material with a high surface area to enable evaporation (Figure 11). The pads sit in a trough that catches water after it has run through the pad. This trough drains to a reservoir with a pump that moves water to the top of the pad to recirculate back through the cellulose material. It is important to note that not all of the water passing over the pads is collected and recycled. Some of the water is lost due to evaporation as the exhaust fan pulls air across the pads. So, water must be added to the reservoir periodically or a float value and water line must be installed to manage automatic refilling of the reservoir. An exhaust fan placed on the opposite end of the greenhouse from the pad (Figures 10 and 11) pulls air through the pad while also

Figure 10. *Evaporative cooling is accomplished as an exhaust fan pulls air out of the greenhouse and pulls air through a pad on the other side of the greenhouse. These fans are available in many sizes to fit a range of greenhouse structures.*

Figure 11. *A corrugated cellulose pad used in a fan and pad system. Water runs over the pad and evaporates.*

pulling the cooler air through the greenhouse. The exhaust fans pull air in through the inlet vents located on the opposite side of the pad and the air pulled across the pads passes through the length of the greenhouse. This cooled air rises in temperature as it passes through the greenhouse, so the pad end of the house is generally cooler than the fan end. This heat gain can be calculated and the distance between fan and pad are carefully managed according to climate requirements.

SHADE CLOTH

Light transmission has already been discussed in regards to photosynthesis and heat gain or loss. The selection of covering materials to manage this relationship is important, but there are also curtains that can be installed on the inside or outside of the greenhouse to support light and energy management.

Shade can be used to manage light and temperature gain. For instance, if summer light levels exceed desirable levels for

Figure 12. A metallic shade cloth installed tightly over the outside of a small polycarbonate covered greenhouse to reflect light and reduce

optimum crop growth, a shade cloth can reduce the incoming light. Additionally, these shade cloths can reduce heat gain in the greenhouse and increase the cooling system effectiveness in reducing temperatures. Shade cloths can be installed on the outside of the greenhouse and left on for the high light season (Figure 12). Some growers also use shade paint which is applied in late spring or summer and provides shading through the summer. It may wear off by fall or may need to be manually removed by cleaning.

SUPPLEMENTAL LIGHTING

A lack of adequate light is the most common factor limiting the growth and quality of plants in winter seasons. Artificial light sources can be installed and managed to support more consistent photosynthesis by increasing the daily light integral (DLI). Several factors must be considered in terms of the potential benefit of supplemental lighting, including the crop, growing season and level of natural light that can be expected on average (Figure 5).

Several different lighting options are available. In the past, many greenhouses were fit with high intensity discharge (HID) lights, such as high pressure sodium or metal halide. These lights, along with reflectors, could be installed over the crop and provide light to support photosynthesis. They also produced heat, which in winter could be positive in some greenhouses. Other common supplemental lighting options were florescent, which generally needs to be installed closer to the plant to provide enough light. These lights are often used in germination areas.

Light emitting diodes (LEDs) are newer options in greenhouse lighting, and there has been much research (Figure 13) and improvements in engineering over the last few years. These lights are desirable for their ability to deliver specific wavelengths of light, be positioned close to crops due to low heat emission and for their long life expectancy. Because of the ability to adjust the wavelength of light delivered to plants, much remains to be understood about these lights and their optimum use in greenhouse settings. The cost effectiveness of LEDs continues to increase.

Figure 13. *Light emitting diode being used as a supplemental light for dwarf tomatoes.*

CONTROLLERS

With this brief introduction of the many individual tools used to manage a greenhouse environment, it is important to conclude with a description of how the operation of these devices can be coordinated. Engineers and technicians, along with the input of growers, have developed several levels of controls that aid in monitoring and automatically controlling the greenhouse environment.

The simplest level of management or control is a single or series of thermostats. These units help monitor the environment and controls when a fan or heater should be turned on or off. Unfortunately, individual thermostats are limited in their ability to link multiple fans or control fan speed because they often have only an on or off control. While thermostats have many limitations, small growers and simple greenhouse spaces may find them a sufficient and effective option.

The next level is a step controller because it offers 2-3 stages of controls. For example, a single step controller can turn on one, two or three fans in a three-fan system, depending on the temperature threshold setting. Sometimes step controllers will offer day and night maximum and minimum temperatures. The down side to these is that some do not offer a data recording feature to track conditions.

A third level of controllers include computer software. They can provide a greater number of stages and split the house into specific zones based on climate needs of the crops in those zones. However, this option may be more costly and complex than desirable for the residential greenhouse. An advantage to using computer software is that as technology progresses there are controller options for computer operation, remote management, wireless features and the simpler and more cost effective opportunity to manage greenhouse climates from a smart phone. Due to increases in flexible, smart technology, small controllers continue to become more cost effective and accessible for small-scale greenhouse situations.

CONCLUSION: LINKING USES WITH IMPORTANT CONSIDERATIONS FOR THE SMALL-SCALE GREENHOUSE

Many considerations are important for the residential or educational grower in terms of selecting the site, design and structure as well as heating and cooling systems for the greenhouse. However, all of these factors must be tied back to the main uses for the greenhouse. To bring this information

Figure 14. A range of edible and ornamental crops are possible in residential greenhouses when planned, designed and managed well.

clearly back to the reasons home greenhouses are installed, this final section provides a few important considerations for each of the main goal areas (Figure 14) for small-scale greenhouses to keep in mind during planning, design and purchase.

PRODUCING GARDEN TRANSPLANTS

- Heating capacity will need to maintain appropriate germination temperatures in late winter and early spring. Keep in mind that warm season vegetable crops and many flowers will require germination temperatures around 80 degrees Fahrenheit and nighttime temperatures between 60-65 degrees Fahrenheit.
- Ventilation for rapid fluctuations in temperature are important for early and mid to late spring conditions.
- Evaporative cooling systems may not be required, but exhaust and circulation fans will be needed for ventilation unless a passive system that is well-designed and functioning is present.
- Access to the highest levels of natural light will be important in early spring for proper transplant growth, so be careful of shaded sites. Supplemental lighting may be needed in low light conditions.
- Insect pests may be less of a concern in early spring, but beware of existing pest levels in the greenhouse when the transplant season begins if the house was used to grow or overwinter other crops.

GROWING FOOD CROPS

- The seasonality of production and the growing systems for crops are crucial factors. Environmental management will hinge on those decisions.
- If year-round is the goal, heating capacity will be needed that can maintain appropriate germination and growth temperatures in the coldest portions of the year. Warm season vegetable crops will require germination temperatures around 80 degrees Fahrenheit and nighttime temperatures between 60-65 degrees Fahrenheit for proper transplant growth. Cool season vegetable crops can be grown using lower night temperatures of 45-55 degrees Fahrenheit, but low temperatures will slow down growth. Keeping the greenhouse above 55 degrees Fahrenheit at night is best.
- Ventilation with exhaust and circulation fans will be needed to manage fluctuations in temperature and to maintain proper humidity.
- If summertime production is intended, evaporative cooling systems (either a fan and pad system or mist or fog) will be required. Even with these cooling systems, temperature control will be limited by the size of the greenhouse and the design. Shading will be essential in summer to manage temperature gains.
- Access to the highest levels of natural light will be important in fall, winter and early spring to support crop growth and productivity. Supplemental lighting may be an asset in low light conditions of late winter, especially if growing warm season fruiting crops.
- Insect pests are a very important consideration. Screens may be needed over vents and careful management of any plants brought into the house will be needed.

FOLIAGE AND FLOWERING PLANT COLLECTIONS

- Heating and cooling capacity will be needed to maintain conditions specific to the crop.
- Light and humidity management are also important for many crops, such as orchids. Families or species within the family may require varied light conditions.
- Sometimes orchid growers will move plants to shade houses in the summer, so seasonal uses may vary.
- Often providing the specific conditions needed for specialty crops is an iterative process of learning what crops need and the microclimate within the greenhouse as well as management tricks and techniques. Many small-scale growers are quite innovative and enjoy the experimentation of managing conditions for specific crops.

MANY OTHER ODDS AND ENDS

- Beware of overwintering crops bringing in pests or diseases. Having a down time in the greenhouse can inhibit pest cycles and provide time to clean and disinfect surfaces.

SUMMARY

Small-scale greenhouses can be an asset to the home gardener or educator in many ways and can support plant growth and productivity beyond the limits of outdoor growing. However, proper design and selection is critical to ensure a high-quality structure that will add value to your property and support your gardening or teaching ventures. Careful selection of the site, structure and covering as well as environmental control will be essential to gain the most value and enjoyment from your residential or educational greenhouse.

SOURCES AND ADDITIONAL READING

Aldrich, R. A., and J. W. Bartok. 1998. Greenhouse engineering. Vol. 3. Ithaca, NY: Natural Resource, Agriculture, and Engineering Service, Cooperative Extension.

Beytes, C. 2003. Ball Redbook: Greenhouses and Equipment. Vol. 2 Edition 17. Ball Publishing. Batavia, IL.

Lopez, R. 2013. The Basics and Beyond: Understanding the Differences between Photoperiodic and Supplemental Lighting. Purdue Extension. leds.hrt.msu.edu/assets/Uploads/Photoperiodic-and-supplemental-lighting.pdf.

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