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Greenhouses and Similar Structures

An Overview

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Thanks to the pioneering work of Dr. Emery Emmert, "The Father of the Plastic Greenhouse" at the University of Kentucky in the late 1940s and early 1950s, the types of greenhouses available today have become much more diverse. We now have many alternative types of structures that can effectively extend the growing season. These range from small, simple greenhouse-like structures (low tunnels) to high tech greenhouses (Table 1), which can be built to form complexes of 40 acres in size or more. Regardless of the chosen structure, the design should protect against wind, snow, and other potential damage to crops while maximizing light transmission.

Figure 1: Plastic high tunnel with ridge vent.

A greenhouse is a "tool" that can be used to facilitate growing plants and protect them from unfavorable climate conditions. **The tool is fitted for the job, and not the other way around. Therefore, "the best" greenhouse structure is the one that best fulfills the grower's goals**, considering crop species, geographic location, growing season, economic feasibility, labor, and market conditions. For example, low tunnels or low-tech greenhouses may be quite adequate to handle the job if the primary goal is an early start at the farmers markets.

This extension publication provides an overview of key factors to consider when selecting greenhouse structures. It covers various structure types, glazing materials, heating, and cooling systems, which will help growers make informed decisions to optimize greenhouse performance, improve energy efficiency and crop production.

Greenhouses in Kentucky

With the overall improvements in greenhouse technology and supportive programs, Kentucky's greenhouse industry has seen steady growth since the tobacco buyouts of the early 2000's. Moreover, the increasing demand for locally grown fresh produce, and Kentucky's prime geographic location—being within a day's drive of a sizable portion of the contiguous United States (US)—have bolstered an influx of greenhouse growers of all sizes. In Kentucky, large-scale and smaller scale greenhouse operations exist with a wide range of technologies in use. Furthermore, Kentucky greenhouses produce a wide range of horticultural products, from soil-grown vegetables to aquaponic-produced lettuces and fish to containerized ornamentals and fresh cut flowers, the crop diversity of Kentucky greenhouses continues to expand.
From USDA census in 2022, there are 6,647,045 sq ft (about twice the area of a large shopping mall) of vegetable and herbs production under glass other protection in Kentucky. This represents a 348% increase in greenhouse vegetable and fresh cut herb production area from 2017, catapulting Kentucky into the top 5 states

in the US. When cross-comparing county data, the total production area does not account for some of the large-scale greenhouses that have been recently constructed and are currently in operation.

Types of Greenhouse Structures

Feature	Low Tunnel	High Tunnel	Basic Greenhouse	High-Tech Greenhouse
Structure	Low, flexible hoops	Walk upright inside, hooped frame	Rigid frame	Steel/aluminum frame with advanced design
Glazing Material	Plastic film, row cover	Plastic film	Polycarbonate or polyethylene	Glass, acrylic or polycarbonate
Height	1-3 ft	6-15 ft	8-20 ft	15-30 ft
Foundation	No foundation, anchored with soil or pegs	No foundation, anchored with stakes	Concrete or metal base	Concrete foundation
Ventilation	Manual	Roll-up sides or end-wall vents	Roof vents, fans, side vents	Automated vents, fans, cooling pads, AC
Environmental Control	Minimal	Moderate (passive control)	Heaters, fans, manual shading	Automated climate control, sensors
Heating	None	None or passive heating	Often heated (propane, gas, electric)	Electric, gas or advanced heating (geothermal, combined heat and power, radiant)
Durability	Seasonal, temporary	Semi-permanent	Permanent	Highly durable

Table 1: Overview and comparison of different types of greenhouses and similar structures

Low Tunnels

Low tunnels consist of wire or polyvinyl chloride (PVC) hoops covered with transparent plastic or row covers. They are commonly used alongside black plastic mulch and drip irrigation. The covers remain in place for only three to four weeks before being removed. Covers protecting bee-pollinated crops should be removed when the first flowers appear. Besides providing an excellent means of extending the growing season, low tunnels also offer wind protection.

Figure 2: Low tunnels covered with insect netting.

Modifications have been made to this basic design to allow for daytime ventilation when temperatures within the plastic begin to rise to levels that are detrimental to crop health. While cucurbits are more tolerant of elevated temperatures, ventilation is necessary for some crops such as tomato and pepper. One way to provide ventilation is to simply place slits in the plastic to allow the heat to escape. Rolling up one or both sides of the tunnel is still another way to provide ventilation. An alternative system involves using two narrower sheets of plastic with a seam at the peak of the hoops. This seam is secured by clothespins, which can be removed to open the tunnel for ventilation. Another method, the double hoop system, makes use of two hoops with the plastic sandwiched between them. Because the edges of the plastic are not buried, the sides of the tunnel can be raised and lowered as needed for ventilation.

High Tunnels The field greenhouse of Dr. Emmert's day is now generally called a "high tunnel" or "hoop house." A high tunnel is a hooped frame of walk-in height covered with plastic. Although lacking the precision of active environmental control, these simple unheated structures do moderate temperatures, provide soil warming, and protect plants from wind and rain. They are used to extend the growing season earlier in the spring and later into fall for a wide assortment of horticultural crops. Additionally, high tunnels maybe be used for the winter production of various cool-season crops, such as leafy greens and herbs. University of Kentucky researchers have investigated the use of tunnels for organic brambles and blueberry production, as well. Tunnels may have a rounded Quonset shape, or they may have the peaked roof of a Gothic style high tunnel (the latter is the most popular option as a standalone structure in Kentucky, due to its superior ability to handle snow and ice-load); they may be a single stand-alone house or form multi-bay tunnels. Standard sizes can vary from 14'x 30' to 30'x96'. Frames, which can be constructed of metal pipe, wood, or PVC pipe, are covered with one or two layers of greenhouse-grade polyethylene; those covered with two layers of plastic additionally have a blower fan to maintain an air layer in between, thus offering better insulation and consequently, more cold protection.

High tunnels may be moveable structures that can be relocated to a new site each season, or they may be placed in a more permanent location. Moving tunnels to different sites can facilitate crop rotation, help avoid salt buildup in the soil and prevent the buildup of insect pests and disease pathogens. The soil in moveable tunnels should be worked prior to erecting the structure. Once the structure is in place, tilling can be a challenge. Pennsylvania State University has developed a design in which the end walls are hinged, and a small tractor or tiller can be driven in. New Hampshire's system uses plastic mulch to cover the entire soil surface under the tunnel, making tilling unnecessary.

Figure 3: High Tunnel at UK Horticulture Farm

Passive high tunnels do not have any external connections, except for the water supply for trickle irrigation and fertilization. There are two main systems for ventilation. In the most common system, the sides of the tunnel are rolled up each morning to provide ventilation as temperatures rise within the tunnel. The sides are rolled back down again each evening for cold protection. A system that is becoming more common has drop-down side-walls. While high tunnels do not have a permanent heating system, some growers choose to keep a portable heater available for unexpected drops in temperature. Extreme caution must be used when doing this, because an improperly vented tunnel can injure the plants and anyone working inside the tunnel. When vented properly, serious foliar and fruit diseases are often fewer since plant surfaces remain dry while in the protective environment of the high tunnel. Also, high tunnels can reduce plant and fruit damage by excluding animals (such as birds) and certain insects (with insect netting). Fewer diseases and pests can mean reduced pesticide use. High tunnel production results in improved crop growth, quality, and yields compared to plants produced in the field without the tunnel. A combination of an earlier planting date, along with the more rapid ripening that occurs within the tunnel, can result in mature tomatoes as much as one month earlier than field tomatoes.

Basic Greenhouses

Basic greenhouses, also referred to as low-tech or mid-tech greenhouses, are generally simple and basic greenhouse structures with limited automated climate control systems. They may be 20 feet or more in width and 100 feet or more in length with frames of aluminum, galvanized steel, or wood. Glazing or covering materials are typically rigid transparent plastic, polyethylene, or polycarbonate. If only a single greenhouse is required, it can be built as a standalone unit. A wide range of structures have been used for greenhouse design, and the most used standalone structures including free standing Quonset (a), gable (b), gothic (c), and round arched with vertical wall style (Figure 1). It's recommended to select the greenhouse frame based on the geographic location, production size, cycle and methods, as well as financial consideration. The pros and cons of different free-standing basic greenhouse structures are compared to help growers make decision (Table 2). However, when multiple houses are needed (either initially or as part of a future expansion), the greenhouses should be gutter connected for more efficient use. Both standalone and gutter-connected greenhouses can collect large quantities of rainwater for irrigation.

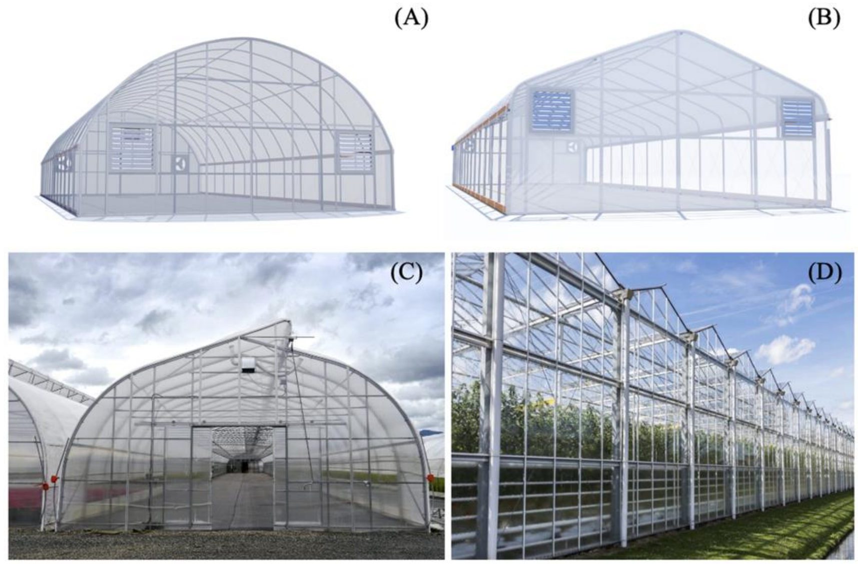

Figure 4: Overview and comparison of different types of greenhouses and similar structures. Quonset (A), gable(B), gothic (C) and Venlo (D) style greenhouses (photos from greenhouse and high tunnel providers)

Basic greenhouses may be carefully designed or upgraded with add-on technologies to improve crop yield and quality. Improvement can be made through increasing ventilation, light transmission and managing nighttime temperature.

	Quonset	**Gable**	**Gothic**
Light transmission	Low	Mid	Highest
Peak height	Low	Highest	Mid
Durability	Low	Mid	Highest
Withstanding snow load	Low	Mid	Highest
Withstanding strong wind	Highest	Low	Mid
Construction cost	Low	Mid	Highest
Operational (heating, ventilation) cost	Low	Mid	Highest

Table 2: Advantages and disadvantages of diverse types of greenhouse structure.

Ventilation is essential to maintain the growing environment within the greenhouse, including temperature, relative humidity, air, and CO_2 exchange. Combining side wall ventilation with roof ventilation increases air flow that is perpendicular to dominant wind, and increasing the height of the greenhouse up to 6-meter could promote ventilation efficiency in removing hot and humid air.

To achieve maximum light transmission for winter production, the greenhouse orientation, the angle of the roof slope, and covering materials should be considered. In Kentucky, east-west oriented greenhouses get more light in winter while north-south oriented greenhouses get more light transmission in summer. Steeper roof slopes will also improve the light transmission in winter.

Since the temperature drop during night could negatively affect plant growth and fruit quality, retractable screens could be considered to reduce nighttime heat loss for unheated greenhouse winter production.

High-tech Greenhouse

When the greenhouse operation is scaling up, muti-span gutter-connected greenhouse should be considered for more efficient resource use. For most high-tech greenhouses, microclimate (lighting, air temperature, humidity, air exchange rate and CO_2) and other factors, including irrigation, growing substrates and nutrient recipes, are fully controlled through mechanical ventilation, artificial lights, heaters, fans, misting system, coolers, and an irrigation system. Therefore, plants are more uniform with higher yield and better crop quality. Venlo greenhouse is the most popular high-tech greenhouse in the world. However, high-tech greenhouses require significant investment in both initial capital and ongoing operational costs.

High-tech greenhouses enable the year-round production of a wide variety of crops, from high-wire vegetables like tomatoes, cucumbers, peppers, and lettuce to high-value crops such as berries, herbs, and ornamental plants. Taking tomatoes as an example, in high-tech greenhouses, indeterminate varieties are grown as they produce flowers and fruits simultaneously throughout the extended period of their life cycle of 10-12 months. Plants are trained vertically against strings, maximizing space usage, and ensuring optimal light exposure. Once the plants begin producing fruits, tomato clusters can be harvested weekly, as new fruit clusters ripen continuously. The vegetative and regenerative growth of tomato plants can be monitored through adjusting crop maintenance (e.g., de-leafing, pruning etc.) and fertigation management. With favorable growing conditions and crop maintenance, high-tech greenhouse tomato growers could reach an average yield of 70kg/m^2 for a 10-month crop cycle. More importantly, the consistent weekly harvest not only maximizes productivity but also ensures a steady supply of fresh tomatoes to the market, meeting consumer demand year-round.

Glazing Materials

Plastic film (polyethylene film), rigid plastics (polycarbonate and acrylic), and glass are the most common greenhouse glazing materials. Each material has unique characteristics that should be carefully evaluated based on light transmission rates, lifetime, and costs (Table 3). Key factors to consider include PAR transmittance, UV transmittance, heat retention, durability, and cost. Some materials offer diffuse or non-diffuse light options and UV-transmissible or UV-blocking properties. Diffuse materials promote uniform light distribution, enhancing photosynthesis in the lower canopy, reducing crop temperature, and increasing leaf count compared to direct lighting. UV-absorbing chemicals may also be added to extend the material's lifespan.

UV transmission into greenhouses has both positive and negative impacts on plants, beneficial insects, pollinators, pests, and pathogens, and should be assessed based on specific production priorities. UV light can promote plant bioactive compounds, enhance stress tolerance, and induce compact growth with smaller and fewer leaves. It can also kill fungal spores and reduce the severity of many fungal pathogens. However, UV light can affect insect navigation and orientation and increase activity from pests like aphids and whiteflies.

Materials	PAR transmission	Thermal transmission	Lifetimes (years)	Costs ($/ft2)
Glass	Highest	Low	> 25	1.25-7.00
Polycarbonate	Mid-high	Mid-Low	10-15	1.25-2.50
Acrylic	Mid-high	Low	20	1.50-3.50
Polyethylene film	Low	High	3	0.06-0.09

Table 3: Photosynthetically active radiation transmission rates, thermal transmission rates, lifetime and costs (based on material area) of common greenhouse glazing materials.

Ventilation

Ventilation refers to the process of air exchange, removing the air inside the greenhouse and replacing it with air from the outside. Ventilation is one the most essential tools to maintain appropriate growing condition (CO_2, temperature, and moisture levels) in the greenhouse.
Greenhouse ventilation is crucial for plant health and growth by regulating greenhouse growing environment, promoting transpiration and nutrient uptake, preventing diseases and pests, and ensuring proper pollination and CO2 levels. Venation in controlled environment structure could be poor in summer, associated with insufficient ventilation methods and surface, leading to significant crop damage and loss. High-tech greenhouses usually have a sophisticated system to actively manage the airflow combining natural ventilation, roof vents, and circulation fans. Lower-tech systems also have some tools to improve ventilation.

The primary ventilation method in high tunnels is rolling up and down the sidewalls, which can be done manually, or using a crank or motorized system. This passive ventilation method relies on natural airflow. Additionally, end wall openings also help improve air exchange.

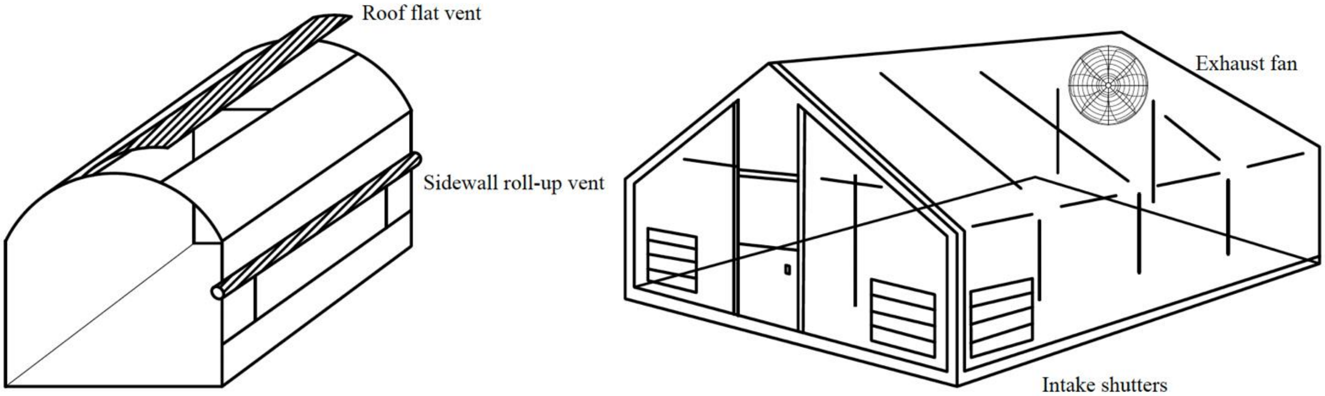

Figure 1: Greenhouse ventilation of sidewall roll-up vent, roof flap vent and exhaust fan system.

basic greenhouses, ridge vents and sidewall vents could be operated manually or thermostat-connected to motorized openers, cranks, or fans, allowing warm air to escape and cool air to enter. However, these fans are often small-scale which may result in non-uniformed airflow, hot spots, and insufficient CO_2 distribution. Fans need to be properly sized to provide enough air exchange volume in the greenhouses. In general, an air exchange volume per minute to a height of 8 to 10 feet is required for summer ventilation, and ¼ volume is needed for winter ventilation. For example, a 30x96 greenhouse would require an air exchange volume of at least 30x96x8 = 23,040 cubic feet per minute (CFM) in the summer. When choosing the fans, it is common to have two or more fans achieving the target CFM to allow for air circulation and to have backup in case of malfunctions. To prevent stagnant air pockets, fans should not be spaced over 25 feet away.

Shading

During the summer months, Kentucky experiences intense solar radiation and heat, which can negatively impact plant growth. Ventilation alone is insufficient to control the greenhouse temperature. To maintain optimal growing conditions, shading is essential for regulating temperatures and light intensities, alleviating plant stress, and preventing excessive strain on cooling and ventilation systems. The two most common methods of greenhouse shading are commercial shading compounds, also known as whitewash, and shade cloth or curtains. Shading compounds are liquid coatings applied to greenhouse glazing materials to reduce light intensity. The level of shading can be controlled by adjusting the concentration and volume of the application. Shade cloth or curtains can be placed on the interior or exterior of the greenhouse, controlled manually or automatically, and are rated in light transmission percent

Heating

Appropriate temperature is essential to plant health and high-quality yields. In Kentucky, greenhouses need to be heated for early production in the early spring and extended production in late fall. Heating could be a financial concern for growers due to high energy prices. Therefore, the type of heating systems must be considered carefully based on the size and structure of the greenhouses, outdoor climatic condition, plant requirement and productivity to justify the costs. Heat can be generated by electricity, combustion of gas, oil, coal, wood, agricultural waste plant materials, or using geothermal energy, waste heat from other industries or solar energy. Heat can be delivered through a hot air system (like unit heaters, poly tubes, and horizontal air flow), or hot water boiler system (like fin pipe, root-zone, and plant canopy heating pipe). Heating systems must be well controlled as the whole crop can be destroyed with one night of heating shut down.

Cooling

In Kentucky, greenhouses often require supplemental heating to maintain suitable temperatures during winter, however; cooling is equally important during the hot and humid summer months. Cooling is typically achieved through air exchange between the greenhouse and the outside environment. Common methods include natural ventilation and mechanical ventilation using fans. Cooling pads can be used alongside fans to lower temperatures, though evaporative cooling is less effective in Kentucky's humid summer climate compared to arid regions and introduces temperature and humidity gradients in the greenhouses. Shading is another option to reduce both air temperature and light intensity during summer. Additionally, some high-tech greenhouses employ high-pressure fogging systems to regulate both temperature and humidity effectively.

Additional Resources

- American Society of Agriculture and Biological Engineers. 2008. ANSI/ASAE EP406.4. Heating, Ventilating and Cooling Greenhouses. ASABE. Joseph Michigan.
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- Portable Field Hoophouse (Washington State University Extension, 2009) http://cru.cahe.wsu.edu/CEPublications/em015/ em015.pdf
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