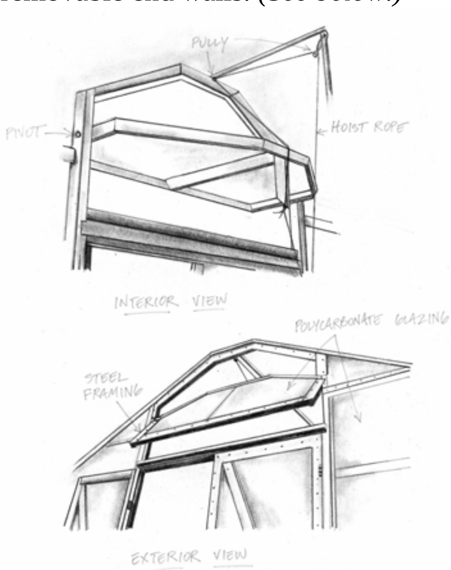
Environmental Management

Ventilation and Cooling

Venting to reduce humidity is more important than keeping the tunnel closed to boost the temperature. The sacrifice of a few degrees in favor of lower humidity will contribute to overall plant health.

High tunnel ventilation is usually accomplished by the passive movement of air through the structure. The air movement through tunnels occurs through roll-up sides, gable-end doors and vents, ridge vents, and removable end walls. *(See below.)*



For growers who also work off the farm, an automated vent is essential. Motorized louvers are readily available, and probably pay for themselves relatively quickly, but solar openers are good alternatives to motors.

The height of roll-up sides should be considered when selecting or designing a high tunnel. The higher the sidewall, the greater the potential air movement through a tunnel. Sidewall height depends in part upon the design of the tunnel. For instance, straight sidewalls—the norm for Gothic structures—allow for higher roll-up sides than curved walls. Longer ground pipes or leg extensions on the bows of Quonset tunnels add height to sidewalls. Gothic tunnels also allow for bigger gable-end vents over the door than Quonset tunnels. Caterpillar tunnels and multi-bay tunnels like Haygroves provide superior venting, since entire sidewalls can be pushed up to allow air passage in both structures.

To prevent tender plants from being blasted with cold air when roll-up sides are vented, some growers are installing a low protective sidewall 12 to 18" above ground level. Poly film, clear acrylic, and polycarbonate have all been used for this purpose. Roll-down side curtains offer another solution.

Large gable-end vents and doors and removable end doors help maximize venting with no energy cost. Retrofitting is feasible, but planning ahead for optimal ventilation during the design phase is best.

Ryan Voiland at Red Fire Farm near Amherst, Massachusetts, purchased a 35' x 120' Harnois greenhouse kit because it seemed the best option for ridge venting. The roof comes to a higher peak in his model than in others. A 24" wide flat piece of plastic at the ridge moves to open the vent. The opening mechanism is powered by a small motor that is activated by a thermostat.

The frame with the ridge vent costs considerably more than a frame without one. Since the frame was also more complicated, Ryan hired a greenhouse builder to erect it. To access the ridge vent, his tunnel has a catwalk on top of the frame. Covering the ridge-vented tunnel with plastic is challenging and follows a different procedure.

Ridge Vents

In ridge-vent systems, cooler air enters the high tunnel through roll-up sides or gable-end openings, and hotter air rises and exits through the ridge vent. These systems work very well, but few high tunnel growers seem to use them, as they are more expensive to purchase and install. Ridge vents can be manually or mechanically operated. Some growers have even constructed their own ridge vents.

An alternative to an expensive full-length ridge vent is a series of small roof vents which act as chimneys to vent out hot air. For several years, Ken-Bar has made an inexpensive roof-installed vent for high tunnels that is available from Farm Tek for a little over $200. These vents have an actual 30" x 14" opening and should be installed every 20' to 25'. A $50 solar vent opener eliminates the need for a noisy motor and an electrical hookup. *(See “Greenhouse Supplies” on page xx.)*

Although Ryan is satisfied with the venting of his large tomato high tunnel, he said he would not opt for a ridge-vented structure again due to the costs and complications of construction. He believes that an exhaust fan could adequately serve the same function.

Fans

Multi-bay and walk-in tunnels can be vented very effectively, but the narrower openings in more traditional high tunnels sometimes constrict airflow. While passive venting is usually sufficient in well-designed high tunnels, several circumstances prompt some high tunnel growers to turn to fans to cool their tunnels, reduce humidity, and improve air circulation.

Photovoltaic Inflation Systems

By Steve Moore

Most traditional hoop houses or high tunnels have only one layer of poly film as a covering, so no blower fan is used. But thermal performance is far better in dual covered structures.

Heated greenhouses typically use two layers of poly film and require a blower. Inflation has two functions. First, it creates a dead air space for insulation. Secondly, it provides turgor to the covering. Keeping the plastic at the right tautness prevents stretching which reduces light transmission. It also prevents tearing.

There are a variety of energy sources to power an inflation fan or blower. For example, Amish farmers sometimes run inflation fans on compressed air to keep within the bounds of their faith. Otherwise, most applications require electricity.

However, not infrequently, high tunnels are located at a distance from grid-connected electrical service. Hook-up can be costly. The alternative we have used is solar photovoltaics—electric power from the sun. Our independent solar power system has worked well for many years.

We used a 32-watt Unisolar flat photovoltaic panel ($210), a Morningstar charge controller, two 6-volt golf cart batteries ($70 - $80 each) and a 12-volt blower fan. With renewable energy, it is cheaper to reduce energy demand than to produce more energy. We were lucky in finding such a fan through a military surplus outlet. This 4-watt blower fan ($20 when available -- see resources) has a very low amperage draw.

The rest of the system is built around the electric demand, in this case, the blower. The blower runs 24/7 so backup batteries are required for nighttime and long stretches of cloudy days. More northerly locations with shorter winter days may require a bigger solar panel and more battery storage capacity.

The two 6-volt batteries are wired in a series resulting in a 12-volt current which is compatible with the charge controller's needs and the solar panel output. In southeast Pennsylvania, the 32-watt solar panel was sufficient to keep the batteries charged for our long-term storage needs (times of little or no sun) and to power the blower and some monitoring equipment. We used a rather expensive charge controller so we could build on it for further expansion of the solar system. Otherwise, several small and inexpensive models ($35 to $100) would be more than adequate.

It is important to protect the batteries from cold. We all have experienced how cold reduces battery efficiency, when we try to start our car on very cold days. With this concern in mind, we chose to place them in a box below grade in the ground in the high tunnel where the earth's constant temperature moderates the cold. We also wanted to get them out from under foot and reduce the chance of spilling or puncturing the cases and releasing battery acid.

You must ventilate your battery box as explosive hydrogen can be a byproduct of battery charge and discharge cycling. We do this with a few holes in the plywood lid. By sizing it big enough, we get double duty out of our battery box. It also functions as an irrigation distribution box to add or change drip tape manifolds and other needs.

The production of trellised summer crops such as indeterminant tomatoes and cucumbers with lots of foliage can reduce air movement. Stagnant masses of humid air result in greater disease incidence. To avoid potential crop loss, it is not surprising that some growers opt for fans.

For winter production, when roll-up sides are buttoned down and doors firmly latched, gable-end vents may be too small to do the job. In this situation, an exhaust fan mounted high at one gable end coupled with a louvered vent at the other can help remove hot air and free moisture and reduce relative humidity in the structure. The louvered opening is controlled with a motor and thermostat.

In addition to an exhaust fan, Slack Hollow Farm uses four small fans hung from purlins to move air in a circular pattern in the 30' x 120' high tunnel. Commonly used in greenhouses, these horizontal airflow (HAF) fans create a gentle air current that moves and mixes air.

The Zemelskys had four HAF fans installed in each of their four 30' x 96'. high tunnels for a cost of $330 per tunnel, including the wiring. In the summer, the added air flow benefits their mostly heirloom tomato crop. However, for winter greens production they do not run these fans. The Zemelskys also use a gable-end exhaust fan in four of their five high tunnels.

Heat stress

Heat stress can be a problem for plants growing in high tunnels that are inadequately vented. When leaf surface temperatures get too hot, photosynthesis and other metabolic activities shut down. Plants close their stomata and stop transpiring. If overheating is allowed to continue, plants will grow poorly, and may eventually die.

A high tunnel full of plants will stay much cooler than an empty one. Transpiring plants release water into the air producing natural evaporative cooling. This is also why misters work well to lower the temperature and why trees, in addition to providing shade, cool down a city street.

Shade cloth is commonly used by greenhouse growers to reduce the interior temperature of the structure. But shade cloth has less applicability to high tunnel growing. In the Northeast, for many summer crops it will reduce light availability too greatly, resulting in poor overall growth and leggy plants.

Shade cloth does make sense for certain species of cut flowers in high tunnels. In southern Pennsylvania, the Cramers effectively use shade cloth in one bay of their Haygrove high tunnel to grow cool-loving (but long-season) lisianthus. This material moderates high summer temperatures and reduces light diffusion, producing the elongated stems required by the market.

Heating

High tunnels are normally defined as unheated greenhouses. Their primary sources of heat are solar energy and the ambient heat of the earth. Farmers don’t use high tunnels to grow warm season crops significantly out of season; instead, they use them to extend the normal season by a period of several weeks. With the additional protection of internal row covers, adequate growing conditions for cold weather crops can be attained, even during the winter months.

For warm season crops such as tomatoes and cucumbers, a standby heating unit can be brought into a high

In-Ground Radiant Heat

In-ground, radiant heating tends to be a less energy-intensive approach than air heating for any structure, whether it is a building, greenhouse, or high tunnel. While relatively costly to install, in-ground systems, which circulate a heated fluid, consume less fuel than heating air, reducing fuel consumption and costs over time. Heating the root-zone stimulates seed germination and root development. In a radiant heating system, a water-antifreeze mixture is heated and circulated with small pumps through polyethylene tubing buried in the ground.

Slack Hollow Farm had been growing year-round in a high tunnel that had neither artificial heat nor electricity. But in their new 30' x 120' high tunnel, Seth Jacobs and Martha Johnson (with the assistance of a plumber) installed a radiant heating system that uses standard, off-the-shelf technology. Seth buried PEX tubing 18" deep, in rows 12" apart, using about a dozen 300' loops for the 30' x 120' tunnel. (Each loop consists of an outgoing and return stretch of tubing.) A 1:1 propylene glycol/water mixture, heated by an oil-fired hot water heater, circulates in the tubing. The heat spreads upward and outward in the soil at a 45-degree angle above the tubing. Once the heat is turned on, it takes about 10 to 12 hours to heat the soil 6" below the surface.

In designing their heating system, they were concerned that the antifreeze mixture circulating in the buried PEX tubing would be too hot for their crops. As a protective measure, they designed their system with all the “bells and whistles,” including dampening valves and return-flow mixing. These added features have proven unnecessary in their application in part because the heater itself can be turned down to 110°F.

For the first winter (2005-06), they chose 47°F as the target soil temperature at a 6" depth. Under the row covers at night, the lowest air temperature was 27°F. It took a single tank of oil (275 gallons, costing $500) to maintain this soil temperature. With the onset of longer days in mid-February, they were able to stop burning oil for the rest of the winter (even though temperatures were cold). They found that the soil 6" down could gain 5°F on a sunny day.

In 2005, before the heating system had been installed, they grew tomatoes in their high tunnel without heat. They warmed the soil to 70°F for their spring 2006 tomato crop, consuming three-quarters of a tank of oil in several weeks during that cold spring. In both years they started wholesaling tomatoes around July 11.

With just one year of experience with their in-ground heating system, it is too early for Seth and Martha to draw conclusions about the economic feasibility of this application. In order to cut fuel requirements, they plan to insulate the soil around the tunnel’s perimeter to a depth of at least 18". The temperature they will eventually choose for soil temperature in mid-spring for summer tomato production is still in question; they hope next year’s trials will help them come to an answer.

tunnel as a temporary safeguard against extreme cold. But when growers install a permanent heating system, they begin to transform their high tunnels into something more akin to a greenhouse.

Nonetheless, farmers are constantly experimenting, and there is much to be learned from their attempts to create superior and cost-efficient growing conditions. While the pros and cons of conventional greenhouse heating systems are beyond the purview of this manual, one example of the use of in-ground heat is presented on page 50. Such a system has applications for growers who wish to minimally heat the soil in their structures just enough to prevent freezing.

Relative Humidity and Temperatures in a High Tunnel

Water condenses on the inside surface of a high tunnel or greenhouse cover when the outside temperature drops below the dew point. Free moisture in the air changes to a liquid state, the same way that dew is formed. When this condensation drips, it can damage plants and promote disease. Droplets of water on the plastic film reflect light away from the tunnel.

High relative humidity increases condensation. Evapotranspiration by plants contributes to the humidity level. Ventilation or heating can reduce moisture levels in the air.

High tunnel temperatures can be measured for the air, soil, or plants. Ventilation directly influences air temperature. Plant metabolism and growth processes affect plant temperature. The intensity of solar radiation affects the temperature of the first inch or two of the soil, but soil temperatures at greater depths are constant. Plant scorching may be influenced more by the intensity of solar radiation than by air temperature.

Adapted from Film Facts, www.bpiagri.com/hort-luminance.htm

Interior Row Covers

Floating row covers are commonly used to further protect plants from cold weather within high tunnels. They are either laid directly over plants or suspended over wire or pipe hoops in the form of low tunnels. Some farmers use plastic film to create tunnels within tunnels. This is a good use for old greenhouse film, as long as it is not so degraded as to prevent adequate light transmission. But plastic, whether new or used, traps moisture and overheats the enclosed space more readily than fabric row covers, and therefore must be opened or ventilated daily.

Alternatively, spun-bonded synthetic fabrics may be used. These include Remay, Typar, Agribon, Agrofabric, and Covertan. These row covers come in a various sizes and weights. Weights range from 0.5 to 2 ounces per square yard. Heavier materials cost more and are less apt to tear. Some are even rip-stop reinforced. The less the fabrics weigh the less cold protection they offer, but the more light they transmit. Because of this trade-off, the jury is out regarding the best weight row cover to choose under different conditions.

In Maine, Eliot Coleman prefers lighter weight materials as they allow more light to penetrate and warm the soil during the day than heavier row covers which provide a few more degrees of frost protection. He does not want to have to open and close inner covers daily. In contrast, while farming in Pennsylvania, Steve Moore used the heaviest weight fabrics for winter high tunnel production. He appreciates its increased insulating ability and durability and has come up with several streamlined systems for moving this material.

In Connecticut, the Zemelskys have used light- and mid-weight spun polyester row cover to assist the crop in germination and protect their hardy greens for winter production. Andy Jones, in Burlington, Vermont, typically covers his winter greens with a single layer of mid-weight row cover, though on occasion he adds a second layer when “super cold” conditions are expected. At Slack Hollow Farm in upstate New York, as many as three or four layers of a medium-weight row cover protect spinach and other greens in the dead of the winter.

At Slack Hollow, the covers are usually removed during the day. Seth Jacobs explains that, in order to take full advantage of solar gain, the ground needs to be exposed to incoming sunlight so it warms up the groundmass, and then insulated from the cold air at night. This concentrates the stored heat from the sun in the ground but eliminates the small layer of air under the cover. “On bitter cold, very cloudy days we might leave some or all of the covers on during the day, but we feel we should uncover whenever possible for maximum light on the plants, and heat gain in the soil,” he said.

Steve Moore follows the same logic as Seth Jacobs for row cover management. On warm, sunny days, he rolls back the covers, while on cold and cloudy days he tends to leave the covers on. However when there is a string of two or more cloudy days, he finds it important to vent on “the best days” as air movement helps prevent and control disease.

In contrast, at the Intervale Community Farm in Vermont, Andy Jones explained that their row cover management is less intensive. “We wait to put them on until fairly late (around late November), but only plan to remove them at harvest or for other chores.”

In a class of its own is Tufbell, one of the heaviest, longest-lasting row cover materials on the market. Made of polyvinyl alcohol, its characteristics are more conducive to winter horticulture than the more common spun polyester. It increases air and soil temperature by 5 to10°F and leaf temperature by 2 to 6°F, yet does not overheat in 90°F weather. It allows 92 to 95% light transmission. Only minimally degraded by sunlight and reinforced against rips, it lasts at least five years or longer if protected in storage from mice and other nest builders. It can also be sewn and washed. However, at 22.5 cents per square foot, it costs more than twelve times as much as Argibon 19 (which costs 1.6 cents per square foot).

Over a period of several years, Steve Moore experimented with a variety of materials in two different configurations, using them as inner grow tunnels on 5' wide beds and also as a 14' wide covering (half the tunnel’s width). He tested the performance of used plastic (greenhouse film), Agribond products, Typar, Agribell, Low-e (1/4 inch foil faced bubble wrap), thermal curtain material, Aluminet, and several others.

He found that used plastic was almost as good as very costly alternatives in terms of thermal protection and heat retention. In fact, he concluded that it is the most economical and environmental choice. He also found that covering half of the high tunnel (14' width in a 30' house) performed better than covering one 5' bed at a time, regardless of the materials used.

The tunnels within a tunnel averaged approximately 18°F warmer than outside temperatures. However, the temperature difference for the five coldest nights was about 26°F. “This is significant,” said Steve. “We want the most protection on the coldest nights.”

Steve was puzzled by some of his temperature readings. He has recorded an outside temperature of 17°F below zero when the temperature in the inner grow tunnel was 17°F above zero. The lettuce growing there was perfectly good and harvested for sale. He attributes the survival of the lettuce to some of the freeze protection mechanisms noted in the section on cold stress physiology and to the effects of super cooling.

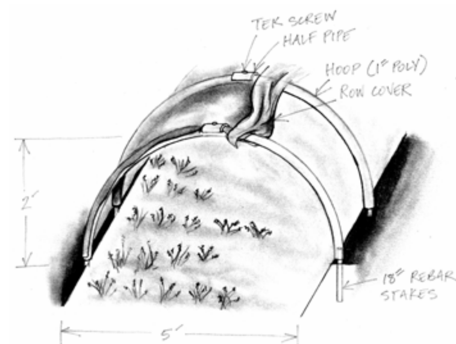
Supporting Interior Tunnels

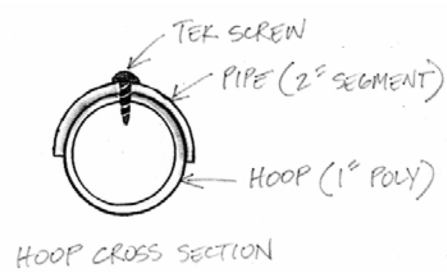
The Zemelskys and other farmers protect their winter crops by laying their “floating” row covers directly on newly seeded ground or over the top of growing crops without any supporting structure. But some growers have experienced a need to support their covers.

For low tunnels in the field, farmers often use hoops of 8 or 10 gauge galvanized steel wire to span their beds. Heavy gauge high tensile livestock wire can also be used. Usually the hoops are about 2' tall and are placed 4' apart. However, for winter production in high tunnels, several growers have noted that steel hoops are not appropriate because they are not tall enough to prevent the cover from touching the crop canopy. Generally plant tissue that comes in direct contact with frozen row cover will become marred and may eventually die.

Steve Moore makes hoops with 8 foot lengths of used polypropylene water pipe (3/4" to 1-1/4" diameter). The pipe ends of the 8' lengths are placed over 18-inch pins pushed three-fourths of the way into the ground on the edges of beds. Row covers may be suspended over these hoops just as would be done in the field.

Attaching the row cover to the bows facilitates ventilation and access to beds for harvest and other horticultural tasks. For each bow, cut a 2" piece of water pipe in half lengthwise. Using either a tek screw or drywall screw, fasten one of these small segments of pipe onto the top of each bow, sandwiching the polyethylene film between. *(See diagrams below.)* To open these mini tunnels, the cover is flung over one side. On a sunny day, the southern exposure is readily ventilated.





Steve closes off the ends of his mini-tunnels with half circles of twinwall polycarbonate or waste polyethylene film. The tunnels themselves are covered with used greenhouse plastic cut to size. Each tunnel spans a single 5' bed, and is about 3' tall.

His tunnels within a high tunnel stay 15 to 20°F warmer than minimum outside temperatures in winter. In sunny weather, he finds it essential to roll or pull up the plastic to reduce unwanted heat within the low tunnels.

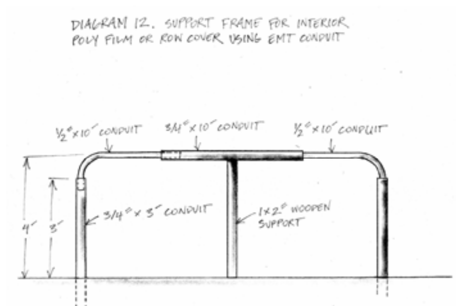
The plastic is also pushed out of the way for weeding, watering, and harvesting.

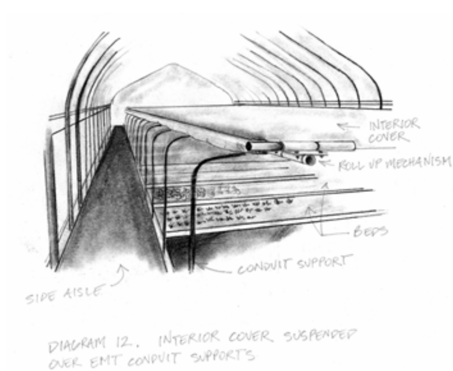
Some of his 30' wide high tunnels are laid out with a center aisle flanked on either side by beds running laterally across the tunnel *(see "Interior Tunnel Layout" on page 57).* Using this configuration, Steve is able to cover half of the cropping area (one side of the entire tunnel) with a single large sheet of row cover.

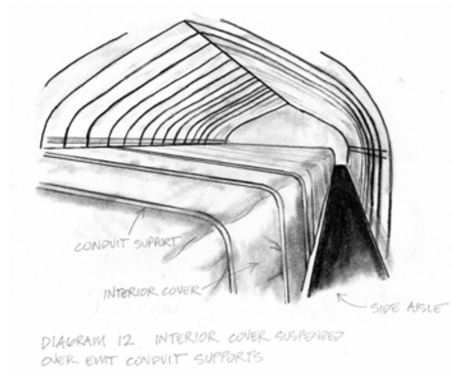
To suspend the row cover above the crops, Steve uses a long, rail-like hoop. He finds the larger, wider tunnel within the tunnel to be more effective in retaining heat than the smaller, single 5' bed inner tunnels. He has even created a roll-up mechanism for convenient venting and re-covering.

His framework for suspending the floating row cover is made of 1/2" or 3/4" thinwall electrical conduit. These metal pipes are spaced 4' on center to line up with the high tunnel bows. Steve bends one end of this metal pipe to a 90 degree angle to support the framework at a height of 30". He supports the middle of the 14' laterals with a piece of PVC pipe and uses a 2" x 4" to attach each metal conduit to a bow. Row cover can be laid loosely over this framework and scrunched up against the sidewall to open up the growing beds. Alternatively, Steve uses a swedged pipe—the kind used for roll-up sides—spanning the length of the high tunnel, to make a roll-up for the row cover. This roll-up is outfitted with a hand crank.

John Biernbaum created a row cover suspension frame almost 4' high for taller crops in his latest teaching and demonstration high tunnel at Michigan State University. *(See Diagram 12.)* The tunnel itself is 30' wide with 25' long lateral beds. Aisles on both sides in the colder and wetter edges conserve the center area for growing. The design uses a horizontal member for every bow and bed, both of which are 4' on center.







For horizontals, two 10' pieces of 1/2" conduit, each with a 90 degree bend on one end, cover 18' of the 25' bed length. A piece of 3/4" conduit in the center spans the remaining 7'. The ends of the 1/2" conduit fit inside of the 3/4" conduit. The 5' vertical support pieces (one at each end of horizontals) are made of 10' long 3/4" conduit cut in half. They are driven about 20" into the ground. The bend of the horizontal conduit raises the height a bit more.

Freeze Damage in Plants

There are three stages of freezing. As it gets colder, first the water in the soil freezes. Next, the water between a plant's cells freezes. Finally, water inside a plant's cells freezes, usually killing the plant.

Freezing of Water in the Soil
Water freezes at 0°C (32°F), yet, in the soil, dissolved solids lower the freezing point of water. When soil water freezes, it actually leaves particles and solutes behind.

In the process of freezing, water expands. While this can cause physical damage to the plant root, at times root cells are able to withstand pressures of up to 1000 atmospheres. This ability to withstand pressure varies seasonally and has been shown to increase with cold hardening. Freeze hardening is not completely understood. It is believed that the seasonal storage of sugars, sugar alcohols, and proteins within the cell aids in lowering its freezing point.

In addition to increased pressure, the frozen ground also prevents plants from taking up water. If they cannot replenish the water they lose through transpiration and other processes, they will die of desiccation (drying out). Winter wind can rob water from plant tissues, exacerbating the requirement for water. Both high tunnels and greenhouses are very effective in protecting against this type of desiccation.

Freezing of Inter-Cellular Water
When water changes phase (i.e., from liquid to solid), it releases significant amounts of energy. Freezing water literally releases heat!

In addition, in freezing temperatures, plants actually expel water from their cells into intercellular spaces. This increases the solutes within the cell, lowering the freezing point of cellular water and protecting the cells. This protective action can keep a plant from structural damage, even if it looks wilted or appears to be frozen.

Freezing of Intra-Cellular Water
Under most circumstances, when the temperature gets cold enough to freeze the water inside a plant's cells, the plant dies. It is ice crystal formation that kills the plant and not freezing per se. Rapid freezing of cells can occur without ice formation. Supercooling can also alter the freezing point, but this is a poorly understood process.

In Walking to Spring, their book about high tunnels on their farm about 100 miles southeast of Louisville, Kentucky, Paul and Alison Wiediger recommend keeping high tunnel plants on the dry side in the cooler months. "We don't let them wilt, but we don't keep them really turgid either…Dry conditions allow plants to accumulate more sugars in their cells, and acclimatize the cells to the cold."

"We can go in the cold frame on a sub-freezing morning (say below 20°F) and all the plants look dead—lying on the ground, you know the frozen look! But by 10 AM or so, especially if the sun is out, they are all upright and beautiful again. It breaks your heart the first time you see it, but it invokes wonder two or three hours later."

"Last year we had the soil at a good moisture level in mid-November and we didn't need to water until February…When we need to water [in the winter], we watch the weather forecast for a window of several days and nights above freezing. We water on the first day of that window, so that by the time the freezing temperature returns, the plants have adjusted to the extra water."