Greenhouses for Growing Food in Cold Climates

How to Design a Year-Round Solar Greenhouse
By Lindsey Schiller, Ceres Greenhouse Solutions
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What is a solar greenhouse? Don’t all greenhouses use the sun? Well yes, but a solar greenhouse uses the sun’s energy not only for growing, but also to provide all of the greenhouse’s heating needs. In contrast to traditional all-glass or all-plastic greenhouses, which often rely on fossil fuels to grow year-round, solar greenhouses can create warm year-round growing environments using only the power of the sun, natural materials and energy-efficient design. As a result, they can grow much more --citrus, avocados, fruiting tomatoes - year-round using less energy, water and resources.
Here are the seven basic elements of solar greenhouse design. By following these, you can create a naturally abundant, self-sufficient, growing oasis, allowing you to grow more with less energy and hassle. For more on designing your solar greenhouse, see The Year-Round Solar Greenhouse: How to design and build a net-zero-energy greenhouse, which includes how-to info as well as many case studies for tailoring your structure to any climate.

1. Orient the Greenhouse Toward the Sun (the South)
This is where solar greenhouse design begins: the sun. The sun is not only your source of light for growth in the greenhouse but your source of heat. Thus, if growing year-round in cold climates, you need to capture enough solar energy through your glazing to heat the greenhouse. Glazing is just a word for transparent materials, such as glass or clear rigid plastics. All these light-capturing materials should face where light is coming in the South if you are in the Northern hemisphere (*For the rest of this article we’ll assume a location in the Northern hemisphere). The sun moves higher and lower throughout the year, but it is always South. A very small percentage of light comes directly from the North, and thus these sides are better off insulated.
2. Insulate the North and Everywhere Else

Solar greenhouse design depends not just on capturing enough solar energy, but trapping it to keep the greenhouse warm enough during cold periods.

This is usually where traditional greenhouses fail: they collect just as much energy as solar greenhouses (and often way too much) but can’t retain that heat when temperatures drop. Solar greenhouse design depends on adding insulation on every surface that is not needed for light collection. This means the entire North wall should be fully insulated. Also, you can / should insulate some of the east and west sidewalls. These only get direct sun for a few hours a day and thus can lose more heat than they gain, depending on your location and climate.

How much insulation is right? It all depends on your climate and site. Look at other solar greenhouses, or contact a solar greenhouse designer who can provide a climate analysis or suggestions, to get an idea.

3. Insulate Underground

Most people think of a greenhouse as four walls and a roof, but they miss a very critical fifth plane: the ground. Just as the greenhouse will lose heat to the outside air when it’s cold, it will also lose heat to the ground below it. The topsoil freezes just like the air, and without an insulating barrier, those freezing temps will enter the greenhouse through the floor.

Moreover, by insulating around the perimeter of the greenhouse, you not only prevent heat loss through the floor, but you also couple the greenhouse to a large store of thermal mass underground. Like other materials – water, concrete, and stone – soil acts as thermal mass, storing energy and slowly releasing it, like a battery. Connecting the greenhouse to this insulated mass helps naturally even out temperature swings.
There are a few different methods for insulating underground. The jist is to install insulation around the perimeter of the greenhouse to create a pocket of insulated soil underneath. This pocket is connected to the soil deep underground, which maintains a steady temperature year-round (often between 40-60 F in most US climates). By insulating around the perimeter, your greenhouse has just tapped into this source of steady year-round temperatures and a large store of thermal mass. This is also the reason why some people partially bury their greenhouse underground. See more on underground, or earth-sheltered greenhouses here.

4. Maximize Light and Heat in the Winter
Solar greenhouse design – and passive solar design in general – relies on the premise of strategically controlling light and heat gain. Namely, you want to maximize light when it is needed (the winter) and reduce light when it is abundant and creates too much heat (the summer).

It’s important to keep in mind the angle of the sun during different seasons, as shown in the graphic above. In the winter, light comes in at a low angle, and in the summer it is much higher in the sky (note these angles vary by your latitude). Thus, on vertical South surfaces, you want to use a high light-transmittance material, such as glass, to absorb as much of this light and heat as possible. You do sacrifice insulation at night, but at this time of year, light and heat gain are the top priority. Thermal mass should be used to store some of this heat for temperature regulation. You can also angle the South face of
your greenhouse so that it absorbs more light (and less is refracted off) as shown in the commercial solar greenhouse below — more on choosing the best angle for your greenhouse glazing in this blog.

5. Reduce Light and Heat in the Summer

In the summer, you have just the opposite problem: for most climates with hot summers, there can be too much light, which creates excessive heat. Because days are longer, light is less imperative at this time of year. Most plants will do better with light-diffusing glazing that has a lower light transmittance, particularly on the roof (where summer light will come in). At Ceres, we recommend a polycarbonate plastic with at least two air pockets for good insulation. You can see a video of this installed on a residential greenhouse here. The roof is the biggest area for heat loss in a solar greenhouse, so using a thicker, more insulated material helps cut back on heat loss through the roof in the winter.

![Commercial Solar Greenhouse](image)

More information on finding the best glazing material for your greenhouse, including sourcing and cost information, is given in The Year-Round Solar Greenhouse.

6. Use Thermal Mass

Thermal mass is any material that can store large amounts of thermal energy. All materials have some ability to store energy, but some have much more than others.
Water, for instance, can store about four times as much heat as air, making it one of the more popular thermal mass materials (or heat sink) used in greenhouses. Other materials are concrete, stone, or the soil underground.

The most common method to add thermal mass is by using large quantities of water because it has such a high heat capacity and is easy to come by. By stacking several 55-gallon drums of water in a greenhouse, the grower can cheaply add a lot of thermal mass. Barrels should be stacked where they are in direct sunlight in the winter and need to be stabilized to prevent from falling. Other methods include building concrete or stone into the greenhouse, such as using a concrete North wall or flagstone floor. Some tips on using water as thermal mass in a greenhouse are in this blog.

**Making mass smarter**

Standard or passive methods of thermal mass are most common but have a couple of limitations. First, you can get micro-climates: the mass will affect the air directly around it, but the warming / cooling effect can be limited to the surrounding area. Second, mass can take up a lot of space in the greenhouse that could otherwise be used for growing.

To overcome these limitations and add extra capacity to thermal mass, there are more advanced systems to make the mass more effective. The most common is store heat in the soil underground using a Ground to Air Heat Transfer (GAHT) system or climate battery. This system uses fans to circulate air underground and store heat in the soil underneath the greenhouse. It also takes advantage of the stable temperatures of the soil underground to provide year-round heating, cooling and some added air circulation / dehumidification.
Running fans does take electricity, but the system as a whole can give you much more of an effect for heating and cooling than passive thermal mass alone.

7. Maximize Natural Ventilation

We’ve talked about passive solar heating in the greenhouse, but this is only one half of the equation. Ventilation is essential to cool the greenhouse and keep plants healthy. Moving air forces plants to grow stronger and reduces problems the risk of molds, insects and pathogens.

To maximize natural ventilation, you want to create a path of least resistance for the air to move. Place intake vents lower and exhaust vents higher to take advantage of natural convection. The intake vent will draw in cooler outside air, and it will naturally rise and be exhausted higher up. The result is additional airflow, without added energy.

It’s necessary to control ventilation (either manually or automatically), so you get the right amount of cooling but not too much. For that reason, I recommend automated vents, either automated solar powered vent openers (which use wax cylinders to open and close without electricity) or exhaust fans — more on different ventilation strategies here. I recommend using more than one method, so you have a back-up. Make sure vents are well sealed and insulated when not in use.
How much ventilation do you need? This is another area that depends on your climate and greenhouse design. We provide some rules of thumb in *The Year-Round Solar Greenhouse*.

The above are the general principles of passive solar greenhouse design. However, it is important to realize a solar greenhouse should be tailored for the local climate. A greenhouse in Maine will require more insulation and different glazing materials than one in Texas. For that reason, get recommendations from professionals or experienced growers in your area when creating your design. The Facebook group *Year-Round Greenhouse Growers* is a good place to start.

**Solar Greenhouse Basics: 1 Insulating your foundation**

![Image of a foundation being built with insulation](image)

Insulating the soil underneath your greenhouse is an essential step for energy-efficient year-round growing. Here are the basics.

The soil underground, if properly insulated, can act as a huge battery for the greenhouse, storing thermal energy and stabilizing indoor temperatures. There are two reasons why an energy-efficient greenhouse needs underground insulation.

Reason #1: Heat loss occurs through the floor

We all know heat loss can occur through a building’s walls and roof, but it can also occur through the floor, accounting for about 15% of an average home’s total heat loss. This is
because the ground, if left un-insulated, freezes in the winter just like the air does. While important for homes, preventing this heat loss is even more imperative for greenhouses because the soil underground holds the plants’ roots (if growing directly in the soil or raised beds). Roots, and thus the plants, will greatly benefit from warm year-round soil.

Reason #2: Soil adds a huge amount of thermal mass

By preventing heat loss to the surrounding topsoil, the soil underneath the greenhouse can now trap and store heat, creating a pocket of warmer soil underground. Soil is a source of thermal mass. Like water, stone and concrete, it stores thermal energy (heat) and slowly releases it later. Insulating underground connects the greenhouse to this huge store of thermal mass. And this mass creates a warmer, more stable year-round growing environment.

Note we do not insulate the bottom of this pocket of soil, but rather leave it connected to the earth deep underground. Why? Because the soil deep underground (below the frost line) is already a stable year-round temperature due to geothermal activity. Neither do we insulate the floor – this should be left un-insulated so the greenhouse so it can absorb heat from the greenhouse. You want heat exchange to occur between the greenhouse environment and the thermal mass of the soil.
At Ceres, we go one step further and actively heat the soil using a Ground to Air Heat Transfer (GAHT) system, aka, climate battery. A climate battery uses airflow through tubes buried in the ground below the greenhouse (thermal mass) to store surplus daytime heat and release this heat during cold periods to maintain favourable temperatures in the growing spaces of the greenhouse.

Even without a GAHT system, insulating underground around the foundation of the greenhouse is an essential measure in building an energy-efficient greenhouse. It helps you extend your growing season even deeper into the winter without having to add extra heat.
How to Install Insulation Underground

There are two primary methods we install insulation around the perimeter of the greenhouse – vertically or horizontally. Which method you use depends on which foundation type you are using.

*Vertical Insulation*

If you have excavated either for a GAHT system or a full foundation wall, you can just slip 4” (2 layers) of closed cell, rigid insulation 4’ down into the earth, so that the top edge is flush with the top of the foundation (shown below).

You have now isolated the soil under the greenhouse from the soil outside, keeping the heat entirely within the footprint of the greenhouse. Remember, don’t insulate the bottom of your excavated pit. The earth has a steadier and warmer temperature 4’ deep, and we want your soil to be able to drain properly.

*Horizontal Insulation (‘Swedish Skirt’ method)*

This method can be used with a slab on grade, with piers if you auger the holes, or if you decide to use no foundation at all. The idea with the Swedish Skirt is that you lay rigid foam board horizontal starting at the base of the greenhouse, and extending 4’ away from the greenhouse. This insulation needs to slope gently away from the greenhouse for drainage, which will require some minimal digging or raking. It’s also best to cover this foam with gravel or soil, as direct UV rays will damage the insulation. Like the vertical
insulation, this system also prevents frozen soil from creeping under the greenhouse, while keeping the warm soil where you want it, directly under your greenhouse.

As always, if wondering how this applies to your solar greenhouse, or you are thinking about installing an insulated foundation, contact us for more tips and advice.

![Diagram of insulated foundation]

Above: excavated area before insulation is installed around the perimeter of a solar greenhouse.
What is a "climate battery"?
A climate battery is a system that pushes warm, humid greenhouse air underground through buried tubing to transfer heat to the greenhouse soil, storing heat energy for times of needed heating. We refer to the system of tubing, risers, manifolds, fans, and the insulated mass of soil it interacts with all as the climate battery. It is referred to as a battery for its capacity to store energy. Also known to be called a subterranean heating and cooling system (SHCS), Ground to Air Heat Transfer System (GATT), geo-air exchanger, or “low-grade” geothermal.

How does a climate battery work?
During the day when the greenhouse interior is being heated by the sun, the climate battery fans push this heated air from high in the greenhouse down through the
underground heat exchange tubing. This warm, moist air cools as it runs through the tubing, depositing heat by conduction into the surrounding soil, and condensed water vapour with latent heat through perforations in the tubing. This cooled, dryer air returns to the greenhouse space, cooling and drying the greenhouse, and regaining its capacity to absorb moisture and heat from the greenhouse again. It is a simple form of the heat pump cycle, that takes advantage of the latent heat energy stored in water vapour, and the phenomenon of condensating said vapour by bringing the air temperature down to dew point through heat transfer to the cooler soil.

**Why do you recommend short runs of heat exchange tubing (25-35’) vs. fewer long runs? Could longer runs be used?**

We have found from experience that 25-35’ runs work well for efficient air-to-soil heat exchange in these systems, but that is not to say that longer runs couldn’t work as well. The issue we have found with longer runs is that after ~35’ often the air has already reached soil temperature and is no longer transferring heat to the soil, thereby wasting the remaining tube length. This also creates uneven heating of the greenhouse soil, with soil near the climate battery intake warmer than near the exhaust. We suspect there are arrangements that could make longer runs work, such as increasing airspeed, but we have not tested it out enough yet to confidently recommend it. Any shorter than 25’ of tube length and you risk not bringing the temperature of the air down to dew-point while in the tubes, missing the benefits of water-vapour phase-change.

**Does the climate battery capacity increase by burying the tubing at greater depths?**

Essentially, yes. But it becomes a matter of diminishing returns, for every bit deeper you install your climate battery, your costs for trenching/excavation and the depth you need to insulate increases. Also, as you go deeper the benefits of soil heat radiated passively back
into the space does not increase, only your capacity for drawing heat out of the soil via the climate battery and heat transfer tubes. We have seen great success in Zone 4 in Colorado with climate batteries installed to 3-4ft deep.

Is there a point at which “charging” the battery becomes useless?
Yes, when your greenhouse air temperature is the same as your climate battery soil. Heat transfer requires a temperature differential to occur. When you have raised your entire affected soil mass to the same temperature as your greenhouse air, then you will find that climate battery intake air temp (same as greenhouse air temp), and climate battery exhaust temp will be equal, and you are no longer storing heat. Your capacity to dehumidify air will be minimal too, for it takes a drop in temperature to induce water vapour condensate.

What does it mean to “properly control” a climate battery?
Good question. To function to your benefit, a climate battery should run only when there is “excess heat” in a greenhouse to “charge” the battery, and when the greenhouse air temperature is below the soil temperature for heating. Also, you do not want to deplete your climate battery of stored heat. This control can be accomplished with a two-stage thermostat (with a low setting, neutral, and high), two separate thermostats, or an integrated controller system that controls other automated systems in the greenhouse.

What does it mean to “deplete” a climate battery in extremely cold weather?
During extended extreme cold events, enough heat energy can be extracted from the climate battery soil to reduce the soil temperature to below the surrounding soil temperature (<50-55°F). At this point, it is better to turn off the climate battery and switch to backup heating.

Can a climate battery be used primarily for cooling in the summertime?
Yes. The first step is to design your greenhouse to reduce sunlight penetration to only what is needed for plant growth, to reduce the amount of solar heat gain. This can be accomplished with opaque siding/roofing and insulation on the north, northeast, and northwest surfaces. Secondly, you will want to maximize the ventilation of your greenhouse, releasing solar-heated air to the surroundings. Next, a high-pressure cooling mist pump can introduce water vapour into your greenhouse environment, effectively sucking up the heat energy in the air and venting to the outside or condensing in the climate battery.

An effective method we've found is by installing a "cooling battery" outside of the greenhouse footprint to the north. The heat exchange tubes in this tubing battery should be spaced further apart 2-3’ plus, and preferably a solar arc food forest should be planted above it, creating a living shade blanket that helps to cool the ground. Mulch is very effective too. This cooling battery can be used to draw cooled, dehumidified air into the greenhouse space.

How important is insulating the foundation?
In short, very important. You wouldn’t build a solar home without insulation, so you hopefully won’t build a passive solar greenhouse without it either. Insulation around the
greenhouse soil serves to hold in the heat stored by the climate battery, without it that heat energy will be transferred through conduction to the colder soil surrounding it. Soil insulation can be as simple as sheets of EPS rigid foam insulation buried around the greenhouse perimeter in a trench to the depth of the lowest layer of heat transfer tubes in the system. If pouring a continuous foundation, those same sheets of rigid insulation can be used in the form system and left in place. Shallow frost-protected foundation insulation systems work well too.

*How important is using perforated pipe?*
Very important. Climate batteries built without perforations in the heat exchange tubing will fill up with water from the condensate, and become "plugged." ADS drainage tubing is available with perforations; it is worth sourcing this material.

*Would it help to insulate below the climate battery as well?*
In theory, this could help, effectively isolating your climate battery soil from the surrounding the soil, limiting the capacity of your climate battery, but reducing heat losses to the earth below. It becomes a question of cost-benefit: insulating your 70°F greenhouse soil from the surrounding soil that may be at freezing down to your local frost depth greatly reduces heat transfer out of your climate battery. Insulating that 70°F soil from the 50-55°F soil below it will reduce heat transfer, but that transfer is already not so significant. Also, with optimum sunny days for climate battery “charging,” you can raise the surrounding soil temperature around your climate battery, increasing your battery of stored heat energy.

*What type of soil do I need for a climate battery?*
Sandy loam soil is very effective and is ideal for plant growth. The soil should be no more than 20-25% clay content and not contain “pottery clay.” Soil with a lot of clay can form a shell around the heat exchange tubing after successive wetting and drying periods, effectively plugging the climate battery. If soil at the site of your climate battery is found to be greater than 25% clay content, it should be excavated, and a different soil mix used for backfill, or the same soil can be amended to reduce the clay content.

*How deep should the climate battery go?*
A typical 3-layer, 4” ADS tubing climate battery can be buried to about 3’4” of depth. This allows for a deep layer at 3’4” deep, a middle layer at 2’4”, and a top layer at 1’ 4”, with 12” of soil above it for the root zone and garden tools. This is just a basic case. In extremely cold climates, a deeper climate battery is recommended, possibly with four layers, to interact with more soil. In a mild climate where a small climate modification is desired, you can go with fewer layers and a shallower climate battery. Denser arrays of heat exchange tubing will exchange heat quickly, but have limited capacity. Less dense arrays will have greater heating & cooling capacity but will be less effective at interacting with all of the soil. Heavy soils will store more heat, and allow for denser heat exchange tubing arrays, while lighter soils hold less heat, and require more spacing between tubes.
A few rules of thumb are:
1) allow 12”+ above the top tubing layer to surface to avoid damaging the climate battery when planting, digging, etc.
2) allow at least 9-12” between heat exchange tubes. Otherwise, your volume of soil affected per tube will be low.
3) insulate around your perimeter to the greatest depth of your climate battery, to keep that stored heat from migrating out to the cold surrounding soil.
4) any tubing deeper than 3’ will store heat below the root zone of plants, and won’t do much to passively heat the space through radiation. Deeper tubes can be considered as “backup” storage but will begin to lose effectiveness.

What’s the best way to install a climate battery?
Sometimes you can install a climate battery by trenching 6” trenches where your tubes must go, and layering the tubes directly on top of each other. This will work for less dense arrays, where horizontal tube spacing is on the order of 2’, leaving enough soil between trenches that they do not collapse.
Often the whole area of the climate battery will need to be excavated, especially if it is determined that a different growing medium will be used as backfill. Excavate to your greatest depth, situate all manifolds and risers so they will not move around during backfill, and start with your bottom layer of tubing. Backfill over each successive layer of tubing, being careful not to drive any heavy equipment over any of the tubes.

Does each tube need to be of equal length, or can some be longer/shorter?
It is best to keep all the tubes as close to equal length as possible, to keep airflow equal through all the tubes. Air flow will be greater through shorter tubes due to their lower friction losses, and the climate battery will lose efficiency from uneven heat transfer.

How big of a fan do you need?
The climate battery fan should have high enough airflow ratings to move the entire volume of the greenhouse space 5x per hour (5ACH). We see the potential for higher air changes per hour, but we will wait for more evidence to confirm. Also, we try to maintain 5fps airspeeds in the heat exchange tubing and keep the air in the tubes for 3-5 seconds. These parameters allow the air to cool to dew point, releasing water vapour and its stored latent heat.

Do you vary the climate battery fan speed to tune the output of the system?
Yes, it is helpful to tune your climate battery with a fan speed controller or variable speed controller. The goal is to maximize your temperature and relative humidity difference between intake and exhaust. This should be done at least twice a year, at the beginning of the heating season, and the beginning of the cooling season.

Have you considered hybrid systems with one climate battery buried 8’ or deeper (“Citrus in the Snow,” Russ Finch style), to serve as backup heat during extreme cold times?
We have not experimented with this arrangement, but thank you, Tim, at Threefold Farm
for having the motivation to try it out. Intuitively it should work great, although depending on your local environment’s low-temperature extremes and the level of insulation of your greenhouse, you may still need additional backup heat periodically. Also, the deeper you dig, the more it costs.

Have you heard of any systems using a greenhouse within a greenhouse to isolate the growing space? How is this best accomplished?
Yes, we’ve seen and recommended this arrangement with great success in many forms. We always recommend the use of a retractable “energy curtain” when the budget allows, effectively blanketing the greenhouse space at night to reduce heat loss, or deploying during hot afternoons for shading. These can be deployed low to create the “cold roof” effect. We’ve also designed “bed batteries,” small climate batteries within insulated raised beds complete with row covers, isolating these smaller growing spaces within a greenhouse for smaller-scale winter production. Simple row covers and cloches within a greenhouse work great too. Check out Eliot Coleman’s book, “Four-Season Harvest,” for detailed methods of simple season extension.

Why do you recommend a horizontal airflow fan? Can these overcome the backpressure in the climate battery?
We have found that horizontal airflow fans work very well, especially for the reduced cost. With large risers and manifolds, and enough heat exchange tubes, the static pressure in the climate battery is relatively low compared to standard HVAC ducting. Initial tests with squirrel-cage blowers led to premature burn-out of their motors. When all vents are closed, the air circulating through the greenhouse and climate battery is essentially a closed system; the squirrel-cage fans would pressurize their intake air enough to speed up their motors, drawing more current and leading to premature failure. They also were very noisy. Inline duct boosters and inline axial fans work very well, but for higher flow-rates (above ~1000cfm), their cost increases dramatically. Make sure to get a fan rated for use in outdoor environments, easily found through a greenhouse supplier (we like J.D.Schaefer fans a lot).

Why is the air pushed into the tubing rather than pulled?
Pushing air creates positive pressure within the climate battery, helping to reduce infiltration of silt into the heat exchange tubes. Also, with the fan on the intake side, the exhaust riser is free for adding cooling mist rings and/or hydronic heat coils. Also, we often locate our intake risers so they can pull from higher above the ground to pull from the warmest air, which in turn helps to protect the fans from irrigation water.

What is the purpose of the manifold? Can all of your heat exchange tubes connect directly to the riser? Could a plastic barrel work as a riser/manifold? Are there other cheap options for the riser/manifold?
The manifolds are an effective way of distributing the heat exchange tubes evenly across the floor area, and to maintain equal tube lengths. Also, it is often difficult to fit all the heat exchange tubes a climate battery design calls for into the surface area of an intake riser alone. Small footprints can be covered without the use of a manifold by using a
plastic barrel as an intake riser/manifold and snaking the tubes around to maintain equal length. Risers have been built out of plywood too, although their lifespan will be greatly reduced when buried compared to plastic. We are very open and curious about other suggestions for materials/methods.

**How should the heat exchange tubes connect to the manifold?**
The simplest way to install the heat exchange tubes is by drilling or cutting a hole and stuffing the end of the tube into it. We use a 4 5/8” hole saw for 4” ADS tubing (4 ¾” for tubing with the nylon sock). With the sock, push the end of the sock into the tube before you push the tube into its hole, to try to keep it on until you backfill. These connections do not have to be air-tight, just tight enough to reduce soil infiltration during backfill. The use of a cheap screw can help to keep the tube in place until backfilled.

**Is the tubing with the sock necessary?**
The ADS tubing that comes with the sock on it is very helpful to prevent the intrusion of dirt/silt into the tubing, especially during installation and backfill. After some period of initial use, most the silt in the soil around the tubing will have settled into its final resting place anyways, but the sock will keep it from entering the tubing in the process. Some dirt and silt in the climate battery tubing is not a big deal, but too much can impede airflow and reduce the effectiveness of individual tubes.

**Could convection tubing (inexpensive vented plastic) be used to direct intake/exhaust location?**
It could be used as an exhaust riser extension, but I don’t think it would stay open under negative pressure at the intake side. We recommend using mylar ducting, available from Grainger up to 18” diameter, for intake extensions to reach up towards the ceiling of tall greenhouses. On the exhaust side, it is not necessary to raise the height and actually can benefit plants with the air movement close to the soil.

**Should I screen my intake/exhaust? If so, how?**
Yes, as a precaution to keep critters out, but more commonly to keep tools and cell phones from falling in! What a pain! Make sure to use large-opening screen (1/4 or ½” or bigger galvanized hardware cloth) to avoid reducing airflow. Window and insect screening is too fine.

**Can the soil be overheated?**
Overheating is not typically a concern, as heat only flows from warmer to colder. Therefore to heat the soil over 90°F, you would need greater than 90°F greenhouse air for an extended period, in which case overheating from the hot air would be more of a concern. The climate battery will lose its effectiveness when the soil has heated up to over 75-80°F, as its capacity to cool will be diminished. For this reason, it is key to pair proper ventilation with the climate battery to dump unwanted daytime heat to the outside during long periods of warm weather. Venting should be controlled to keep the greenhouse space warm and humid during heating seasons, storing heat with the climate battery for night time heating. In the cooling seasons, the venting can be used to release excess heat, saving the climate battery for a cooling source when the outside air is above 85-90°F.
Do you have problems with critters entering the climate battery?
It hasn’t been an issue, but we do recommend the screening to prevent animal intrusion. Insects and such don’t seem attracted to it, likely because of the near-constant airflow. We could imagine a rat or mouse wanting to make a home in a climate battery, but this hasn’t been the case. By keeping the level of the intake/exhaust risers 2’ + off the soil, animals are further discouraged from climbing up into a slippery-walled plastic pipe. Any closer to the ground and a screen should be implemented.

Don't you get mold or mildew in a system like this?
No. For two reasons at least: 1) the air is constantly flowing enough to prevent any molds or mildews from establishing themselves. Molds & mildews seem to prefer stagnant, moist air to flowing air. 2) the perforated tubing is in intimate contact with the soil microbes around it, which are competing for the same territory to live in. Normal soil with active biota in it is too competitive for one organism to win out over the others, and take over.

Do you still need supplemental heat with a climate battery in place?
We often recommend a backup heater be paired with a climate battery in cold climates. On very cold nights, unless a greenhouse is extremely well insulated, the heat loss to the outside environment can be greater than what the climate battery can provide, causing a steady drop in greenhouse interior temperature. Especially after several weeks of cold, cloudy weather, the climate battery will have used up much of its stored heat energy, and could potentially cool the soil to below its average temperature of 50-55°F. At this point, it is recommended to turn off your climate battery fans and run backup heating to heat the space.
For example, at CRMPI, the climate batteries in the Phoenix greenhouse are sufficient to keep tropical plants alive through the majority of winter nights. But, when outside temperatures drop far below 0°F, to -15 or -20°F, the sauna is used as backup heat to keep the greenhouse air temperature from getting too cold and to avoid cooling the climate battery soil significantly.
How to Choose a Glazing Material for a Year-round Greenhouse

Below is an excerpt from The Year Round Solar Greenhouse. For more on choosing a glazing material for a greenhouse, plus costs and tips for installing glazing materials, please see the book.

We live in a plastic-laden age, so when it comes to choosing a material for a year-round greenhouse, the choices can get overwhelming. Polycarbonate, polyethylene, Polygal, Lexan…? Knowing how to navigate the array of ‘polys’ – and other materials like glass – is a major hurdle for first-time greenhouse builders.

Below, we run through the major categories of plastics and glass for a year-round greenhouse. As background, our specialty is energy-efficient, year-round greenhouses that use passive solar greenhouse design. However, this overview can be used for any structure, from low-cost hoop houses to high-end conservatories.

How to Choose a Greenhouse Glazing Material

Before diving into the specifications of the materials, it is helpful to know how to evaluate them. The best choice for your greenhouse depends on your climate and growing goals. Do you want to grow year-round despite freezing winter temperatures? A multi-layer insulating material that can be well-sealed will greatly benefit the greenhouse. Or, do you live in a mild climate and only want to grow cold-hardy crops through the winter, or not grow in the winter at all? A single layer rigid plastic or polyethylene film may be the best choice. To evaluate a material, consider the following factors:

- **Cost** – Consider both upfront cost and lifetime cost, based on how often it is replaced
- **Durability / Longevity** – Several factors play into how long the material will last. Consider the wind and snow loads at your site when weighing this factor. Also consider whether your greenhouse requires a building permit, in which case the structural loads of the material will have to meet building standards.
- **Warranty** – This varies by manufacturer and product; some materials come with a warranty against accidental breakage and hail damage.
- **Light Transmission** – How much light the material transmits is a very important factor for the performance in a year-round greenhouse. But, it can be difficult to ascertain the ‘right’ amount of light transmission. It greatly depends on your climate. For most year-round greenhouse growers with low light in the winter, the higher the light transmittance, the better. Greenhouses in sunny climates will likely benefit from lower light transmission or some shading. Importantly, higher light transmission is inversely correlated with insulation. Materials that transmit more light are thinner and usually, have lower insulation ratings. This makes it a tricky balance for most growers. ([Get in touch with us](#) for a climate analysis of your greenhouse if you want a specific recommendation.)
• **Insulation** – For most climates with cold winters, higher insulation ratings are better. Additionally, greenhouses in very hot climates will benefit from more insulating glazing materials as they will block heat from entering, and keep the greenhouse cooler. Insulation is rated in R-value (higher numbers are more insulating). Sometimes, the inverse rating – the U-value — is also given.

• **Transparent v translucent** – Transparent materials are those you can see through, like a window. Most double layer plastic glazings are *translucent*: they diffuse light and can’t be seen through. Translucent materials are usually better for growing; however, clear view windows provide a nicer view.

• **Availability** – Many materials must be specialty ordered from distributors. Single-layer polycarbonate or fiberglass may be available from local hardware stores in your area. Shipping costs are another factor when choosing a material.

**Rigid Plastics**

**Polycarbonate**

Polycarbonate is probably the most common material today for backyard and commercial year-round greenhouses, due to its many advantages:

• Lightweight and easy to install
• Hail-resistant
• Can hold up to high wind and snow loads
• Long-lasting – many products come with a 10-year warranty
• Can create an insulated greenhouse
• Can be high light transmittance
• Can be sealed well to the greenhouse, often with attractive aluminum trim
Ceres polycarbonate greenhouse roof

The disadvantages are that it will eventually yellow over time with sun exposure, but in recent years the quality has increased greatly. Typical life spans are 10-20 years. It is a greater cost compared to polyethylene film, but generally provides more durability, insulation and a nicer aesthetic.

The fact that polycarbonate can be insulating makes it a good choice for an energy-efficient year-round greenhouse. There is a huge range of polycarbonate products, from standard double layer (8 mm) to 5-layer product (32 mm and an R-value of 5.6, similar to many home windows). They also provide different rates of light transmission – from very high (over 90%) to under 50% for thicker and tinted varieties. Thus, the grower can select a polycarbonate material to suit their climate. Growers in hot climates can reduce heat gain with a lower light transmission product; while those that struggle with freezing winters can retain heat with a thicker, insulating material.
Greenhouse Polycarbonate options for Polygal materials

The most common products are one or two-layer products. These are cheaper upfront, but less insulating and thus decrease the energy-efficiency of your greenhouse. For those in climates with freezing winters, that means you will probably have to heat a year-round greenhouse. The investment in a more insulating, double or triple layer polycarbonate product is almost always worth it financially if you desire to grow year-round and you live in a moderate to harsh climate. At Ceres, we typically choose something in the middle – using a triple-wall 16 mm product that has a light transmission value of 77% and an R-value of 2.4 – for most year-round greenhouses.

You can find polycarbonate through distributors – often those specializing in greenhouse plastics and coverings. The largest brands are Polygal and Lexan. Their websites can also connect you with distributors in your area.

**Acrylic**

Acrylic and fibreglass were the main rigid plastic glazings used before polycarbonate dropped in cost and improved in performance. Commonly known by its trade name “Plexiglas,” acrylic is similar to polycarbonate in many ways. It can come in a multi-
walled form, making it a good choice for roof and wall applications. It can also be bent over a shallowly curved frame. Acrylic is slightly less impact resistant than polycarbonate—it will shatter more easily—but is still very strong as a material. (Acrylic has 17 times the impact resistance of glass. Polycarbonate has 250 times the impact resistance of glass.) Because acrylic and polycarbonate are so similar in regards to performance, we recommend making a decision based on distributors and costs in your area. It is likely that polycarbonate will be more widely available and cheaper to procure.

*Fiberglass*

Fiberglass is made by embedding shards of glass fibers into plastic resin. Most varieties are opaque; it’s used in storage tanks, sports helmets, boat hulls, etc. Translucent varieties (typically a milky color) can be used for greenhouse glazing; however, they have lower light-transmission. Be aware that it is also flammable, and it often has a rough texture that can trap dirt and further reduce your light transmission. Though fiberglass used to be common in greenhouses, today it has mostly been replaced with polycarbonate.

*ETFE*

ETFE is a relatively new product that presents many of the same advantages as polycarbonate – lightweight, good insulation and light transmission, hail resistant and long life-spans. It also has some further advantages – thicker materials can be curved over bent frames, as shown in the aquaponics greenhouse below. Currently, the primary challenge with ETFE is sourcing. As of this writing, there are only a handful of suppliers in the US. Investigate to see whether it is an economical product to be shipped to your year-round greenhouse.

Aquaponic Greenhouse from Friendly Aquaponics in Hawaii
**Film Plastic**

**Polyethylene**

Polyethylene is film plastic is extremely common in the commercial greenhouse industry, primarily because of its low-cost (usually only cents per sq. ft.) It is often rolled over hoop houses or other three-season structures. Though cheap, polyethylene has disadvantages from a performance perspective:

- Short life-span – the material will degrade under UV rays and can easily be torn off in wind or snow, and get damaged in hail. Typically products last 2-4 years in harsh climates.
- No insulation – as thin plastic, polyethylene provides some crop protection, but on its own does not do much to retain heat on cold nights. For that reason, growers often use two layers of the material and a blower to create an air gap in between. The air gap provides some insulation. Alternatively, some growers – notably Eliot Coleman in Maine – use row covers in their polyethylene greenhouses to provide additional insulation, as shown in the photo below.

Considering those points, we consider polyethylene a good material for season extension, and growing in mild climates. Alternatively, you can grow cold-tolerant crops in harsh climates. Due to their short lifespan and lack of insulation, we typically don’t recommend them for a year-round greenhouse in a harsh climate.

**SolaWrap**

SolaWrap – previously called PolyKeder is a higher quality film glazing. It has an R-value of 1.7 per inch, making it less insulating than many polycarbonate products, but much more insulating than polyethylene. It is also much longer-lasting than polyethylene, making it a good choice for curved greenhouses (domes or arched greenhouses) that want to grow year-round in moderate to harsh climates.

**Glass**

Glass is the outlier of the choices above, which are all made out of plastic. Compared to plastic, glass presents several pros and cons.

Advantages of glass:

- Transparent – Glass windows provide clear view windows. Installed in vertical walls, this can make a year-round greenhouse feel much more open, more like a sunroom than a small enclosed box. Many growers also choose them for their aesthetic, which can blend easily with a home.
- Insulation – There are a huge range of glass windows, and many have very high insulation ratings. In addition to having high R-values glass windows can also be sealed very well to the greenhouse frame. Many plastics, in contrast, experience
high levels of thermal expansion. This causes air leaks, which reduce the overall efficiency of the greenhouse.

- **High light transmittance** – Most glass windows have very high light transmittance, over 80%. We recommend selecting clear glass windows, over any tinted varieties that will dramatically reduce light penetration. Low-emissivity (low-e) windows are a slightly more complicated category we discuss further in *The Year-Round Solar Greenhouse*.

- **Moderate cost** – Windows are cost-competitive with a triple-wall polycarbonate, though still vastly more expensive than polyethylene film and single-layer rigid plastics.

**Disadvantages of glass:**

- **Weight** – Glass is dramatically heavier than plastics. That, in turn, makes it harder to install in roof applications. The greenhouse roof requires much sturdier framing, which increases the cost.

- **Can break** – The ultimate disadvantage of glass is simply that it can easily break under hail or falling objects. This makes them hard to use in roof applications. If your greenhouse requires a building permit, glass skylights or windows in the roof need to be tempered, which makes them far more expensive, often exorbitantly so.

Given those pros and cons, we recommend using glass strategically – taking advantage of its use as view windows and using it in vertical applications of the greenhouse walls. It is more challenging to use in a roof application.
5 Tools for Planning an Energy-Efficient Commercial Greenhouse

With demand for local food continuing at a strong pace, a year-round greenhouse is often a good business venture. You can greatly improve your chances for a successful greenhouse business with proper planning.

Planning for a greenhouse business requires basic business planning — thorough research and usually spreadsheets. Here are five essential tools to aid that process, based on the purposes they serve. (Note – these tools do not substitute for all the planning necessary to create a successful commercial greenhouse. “Starting a Greenhouse Business” by the University of Alabama Extension is a good overview of the whole process.)

1. Basic Budgeting and Planning

**Tool: Courses & crop budget templates**

Understanding the cash flow and upfront expenditures of a commercial greenhouse is a crucial step to planning your venture. This will require several steps of research (soliciting quotes for an energy efficient commercial greenhouse kit, for example). To assist, there are courses designed for small-scale farmers and commercial greenhouse growers.

- Bright Agrotech hosts several of these, through their [UpStart University](#).
- If growing with aquaponics, a commercial greenhouse grower can take advantage of several in-person multi-day courses, such as [The Flourish Farm Aquaponic Course](#).

If you are unable to take a full course, you may benefit from simple online budgeting tools. Crop budget templates, available for free from many university extension services, can help a beginning grower create a cash flow plan. These templates act as a profit and loss sheet for a year-round commercial greenhouse: they detail revenue streams and expenses for a typical commercial greenhouse.

A Google search of “crop budgets greenhouse” will yield many resources for a beginning year-round greenhouse grower. You can find general templates for commercial greenhouse and then customize the model to suit your operation.

2. Evaluating your Greenhouse Site
An energy efficient commercial greenhouse requires sufficient light levels for good production. Low light, particularly in the winter, will severely hinder the production and profitability of a year-round commercial greenhouse.

There are several ways to evaluate the light conditions of your greenhouse site. To get a general idea, talk other growers or in your area. Secondly, climate data and information light requirements of specific crops can help you predict what will grow well at what times of year. The brief paper from Purdue University — Commercial Greenhouse Production: Measuring Daily Light Integral — is a very valuable document. It gives light requirements for many ornamental plants and some vegetable crops, as well as generalized light levels for different regions of the US. NREL and many other organizations provide similar maps, but generally, have different metrics for light quantities. For more on predicting light levels and productivity, see the chapter on siting a greenhouse in The Year-Round Solar Greenhouse.

Once you have a general idea of light levels in your climate, you can get more site-specific. Light meters measure light intensity over some time at a specific location. They are useful if there are nearby obstructions, like trees or buildings, that could shade your greenhouse. The LightScout DLI 100 from Spectrum Technologies is a low-cost and very basic meter that sits in the ground. It will give a basic light reading over 24 hours. The advantage here is that it gives a single average reading for a whole day. More advanced light meters are much more precise, but give readings only for a single moment in time. You must take many readings, or connect the light meter to a data logger, to get a full picture of light conditions at your greenhouse site.

Spectrum Technologies DLI LightScout 100 Greenhouse light gauge

Beyond light levels, there are several other considerations that go into selecting a site for an energy-efficient greenhouse, including building regulations and access to water and electricity. For more, see our blog on siting an energy efficient commercial greenhouse.
3. Create a Planting Schedule

**Tool: Crop Scheduling Software**

You’ll need to create an accurate planting schedule, detailing when plants will mature, and how quickly you can generate sales. Seed packets, online research and growers advice are the typical resources to estimate how long a crop will take from seeding to sale. Advanced commercial greenhouse growers can also take advantage of a “decision support tool” called FlowersOnTime™.

This is an Excel-based program that simulates the effect of air temperature on a range of floriculture crops. It allows you to estimate production times based on a variety of conditions, helping you plan your crop schedule and revenue stream. Though it takes some time to learn, it can greatly help you dial in your production schedule, and thus refine your plan for sales.

4. Forecast Energy Costs

**Tool: Online Heat Loss Calculators**

Energy costs are the third largest expense for American commercial greenhouse growers (after labour and material costs), according to research by the University of Wisconsin-Madison. How much you need to heat and cool the greenhouse will have a major impact on your bottom line. Online heat loss calculators help estimate the energy costs of a commercial greenhouse, and narrow done a major line item of your budget.

Heat loss calculators allow you to estimate the energy costs of a greenhouse and predict the impact of certain changes, such as how much energy will be saved if you upgraded your polycarbonate glazing to a more insulating material. Several online heat loss calculators are available; a thorough one is available from the National Resource Conservation Service (NRCS) here.

Virtual Grower is another free software program created by USDA, intended for very thorough commercial greenhouse growers. It is a very large file and somewhat esoteric but packed with functionality: you can create a three-dimensional model of your greenhouse, do a basic energy analysis, and estimate a crop schedule.

A greenhouse designer can also do a thorough energy analysis of your structure, to help estimate the most cost-effective design for your climate. An energy-efficient commercial greenhouse can reduce operational energy costs by over 50% compared to traditional greenhouse structures, which will majorly impact profits. Using passive solar greenhouse design; higher quality, insulating materials, and renewable energy systems – such as a Ground to Air Heat Transfer system – can lower your operational expenses.

5. Start Sketching
**Tool: 3D Modeling Software**

An energy efficient commercial greenhouse should be professionally designed and engineered. Typically, a professional — either a greenhouse consultant, architect, or the greenhouse manufacturer — provides this step, but you can also do a great deal of drafting on your own to start planning, and help communicate your ideas. SketchUp is a free, three-dimensional modelling tool and relatively easy to learn for those without drafting or CAD experience. You can create a 3D rendering of the greenhouse with accurate dimensions, and your particular specifications.

![SketchUp Model for an attached solar greenhouse](image)

A basic rendering of your ideal commercial greenhouse can help facilitate talks with contractors, manufacturers, and/or your local building department. It can also be particularly useful to lay out the interior growing systems and floor plan. You can draw in the growing equipment, walkways, work areas, storage space to get a sense of your interior space. Finally, SketchUp can ‘geo-locate’ the drawing, inputting climate data for your specific location. A ‘shadow’ function can allow you to see how light interacts with your greenhouse at different times of day, and over the course of the year, helping you predict which areas of the greenhouse will be fully illuminated (i.e. highest productivity) and which will be shaded.

What are your challenges in planning a greenhouse business? [Let us know](#).
3 Ways to Heat Your Greenhouse for Free this Winter

Learn how to harness and store solar energy to keep your greenhouse growing through the winter for free (or next to nothing)

Greenhouses can be interesting environments to grow in. This is because standard greenhouse materials like glass and plastic (“glazing”) are extremely good at letting in light and heat in, and extremely good at letting heat out. With so much glazed surface area, greenhouses usually overheat during the day if uncontrolled. And because glass and plastic provide no insulation, at night they loose all that heat, causing them to freeze. Take this October day in Boulder, Colorado for instance: An full-polycarbonate greenhouse fluctuated from a high of 110 F to a low of 30 F in one day. Plants, like people, do not like this.

The primary challenge with greenhouse growing is stabilizing these temperature swings. Conventionally, people do this by blasting energy via heating or cooling systems into the greenhouse. But the smarter, more sustainable way of creating a stable year-round greenhouse is to harness the excess solar energy coming in during the day, store it and use it at night. Or, if working with an existing greenhouse, to add an efficient heater that
uses cheap and renewable fuels. These strategies all take understanding and research and have some upfront cost, but the pay-back in terms of year-round growing and long-term savings is well worth it.

Also, remember there’s no cheaper energy than the energy you don’t have to use, so if designing a new greenhouse, create an energy-efficient greenhouse that does not require much heating and cooling in the first place using passive solar greenhouse design. This means using building an air-tight, insulated structure, using proper roofing materials, and orienting the greenhouse with the glazing facing South – where all our light in the Northern hemisphere comes from. If growing in an existing greenhouse, you can insulate your greenhouse and weather-strip air leaks, among other things. Reducing your energy requirements by creating a thermally stable, energy-efficient greenhouse is always the first step.

1) Store solar energy in thermal mass

The easiest and most common way to even out the temperature of your greenhouse is to utilize thermal mass, also called a heat sink. Thermal mass is any material that stores thermal energy. Most materials do this to some extent, but some do it much better than others. Water, for instance, holds about two times as much heat as concrete, and about four times as much as soil.

Incorporating mass does two things. First, it absorbs excess energy during the day, creating a cooling effect. When the temperature drops at night, it starts releasing that energy, thereby ‘heating’ the greenhouse. Note: though I say ‘cooling and heating,’ the thermal mass is not providing the energy, it’s simply storing it and releasing it later, like a battery. The size of the battery (or how much energy you can store) depends on the heat capacity of the material and how much mass you have. Below is a quick comparison of a few different sources of thermal mass and their heat capacities.

<table>
<thead>
<tr>
<th>Thermal Mass</th>
<th>Specific Heat Capacity by Volume J/(cm³*K)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Air</td>
<td>0.001</td>
</tr>
<tr>
<td>Water at 77 F</td>
<td>4.18</td>
</tr>
<tr>
<td>Concrete</td>
<td>2.11</td>
</tr>
<tr>
<td>Wet Soil</td>
<td>1.28</td>
</tr>
<tr>
<td>Dry Soil</td>
<td>0.88</td>
</tr>
</tbody>
</table>

**How-to**
The most common way to use thermal mass is water barrels because it has such a high heat capacity. By stacking several 55-gallon drums of water in a greenhouse, the grower can incorporate a lot of thermal mass. Barrels should be stacked where they are in direct sunlight, often on a North wall. Since plants will be warmer around the water barrels, put more tender plants – like seeding trays or warm weather crops – on or near the barrels. If designing an aquaponics greenhouse, the fish tanks have the nice benefit of doubling as thermal mass. Other variations include building concrete or stone into the greenhouse – such as using a concrete North wall or flagstone floor. Even the soil in raised beds will add thermal mass.

While the easiest to install, thermal mass can be slow to react. It takes longer to disseminate the heat throughout the greenhouse, limiting its effectiveness. But, given the low upfront cost, adding thermal mass to a greenhouse is a popular method for extending the growing season. It may not get you year-round growth of all things, but it can certainly take your greenhouse to the next level.

2) Incorporate a heat exchanger

To go one step beyond standard thermal mass, you can incorporate a heat exchanger to circulate air through the source of mass. This is what we call the Ground to Air Heat Transfer (GAHT) System, but it also goes by other names, like a Climate Battery or a Subterranean Heating and Cooling System (SHCS) – a name popularized by John Cruickshank of sunnyjohn.com.

There are many configurations, but the mechanism of energy transfer and storage is always the same. When the greenhouse heats up during the day, a fan pumps warm, humid air from the interior of the greenhouse through a network of pipes buried up to 4’ underground (most systems consist of a couple of layers of tubes buried at 4’ and 2’ below the surface). The drop in temperature forces the water vapour to condense, and in that process (called a phase change) energy is released. That energy is stored in the soil, causing the soil to heat up. Thus, the process creates a large mass of warm soil underneath the greenhouse year-round. At night, when the greenhouse drops in temperature, the fan kicks on again and extracts that heat from the soil. It’s a relatively simple, time-tested system; ground to air heat exchangers have been used in homes for decades.
A ground to air heat exchanger works very well for two reasons: First, the amount of available mass (the size of the battery as we mentioned before) is huge. For example, there are 768 cubic feet of soil beneath a 12’ x 16’ greenhouse, assuming a 4’ depth. If you lined the whole North wall of the same greenhouse with two rows of 55-gallon water
barrels (16 barrels), they would have a total of 118 cubic feet of mass. That means, using the volumetric heat capacities in the table above, the underground heat exchanger has about twice the capacity as the water barrels. Moreover, because a ground to air heat exchanger connects to the deep earth and thus theoretically has an infinite capacity. For a diagram to better understand this, see our diagram here.

Secondly, because air is actively being pushed through the ‘battery,’ it increases the rate of heat exchange. The hotter / cooler air is distributed around the greenhouse more evenly, preventing cold pockets. Additionally, using fans allows you to use the mass when you want: a thermostat kicks the fan on and off at certain set temperatures. I.e. the fan will start pumping warm air down into the soil when the greenhouse reaches a set temperature (say 80 F), and draw it back up when it has gone below 50 F. Thus, an underground heat exchanger gives you some control over thermal mass; it’s kind of like taking thermal mass and making it smarter.

**Variations**

The material of the battery can vary. Some people backfill the area underneath the greenhouse with gravel or stones instead of soil. If you already have a greenhouse, or can’t excavate on your site to do much groundwork, you can create an alternative battery above ground. You can build an insulated mass of soil or other material, such as a box of river rocks in front of the greenhouse. The system works the same way; only the location of the thermal mass is different.

**3) Use an efficient renewable-powered heater**

The above systems show you how to harness the sun and store solar energy, which is a good first step to natural heating. If additional heating is needed, consider a highly efficient heating system that runs off of cheap and renewable fuel.

One of the common systems used in greenhouses is the rocket mass heater, a super efficient variation of a wood stove. Instead of just exhausting hot air straight out of a chimney as a standard wood stove does, the rocket mass heater first circulates the hot air through a mass of cob, brick or stone before it’s exhausted out. The air warms the mass which holds the heat and slowly radiates it back into the greenhouse over a long period, even after the stove is done burning. The rocket mass heater also uses a double combustion chamber, making it much more efficient than a standard wood stove – a couple of hours of a burn with a small amount of wood can heat a greenhouse overnight. Most rocket mass heaters are DIY systems; you will have to investigate and design a system that fits for your greenhouse using the plethora of plans and explanations online.
Another common greenhouse system is the compost-pile heater, which relies on the magic of aerobic bacteria to break down organic material and give off waste heat. Like the underground heat-exchanger, a compost heater also relies on a heat exchanger: water is circulated through tubes running through a large compost pile. Because of the aerobic decomposition, a compost pile can maintain temperatures of 100-160 F. The heated water is then circulated through the greenhouse where it dispenses heat. Of all the systems, this one probably takes the most tinkering to get right and keep going. You must first build your compost pile with the right material and consistency to get it to a high temperature and keep adding to it or re-building the pile as it decomposes. However, a large, properly constructed pile (see picture below) can keep a 1,000-2000 sq ft greenhouse heated for winter. For these reasons, compost pile heaters are often best suited for larger greenhouses.
Summary

Which way to go? Several factors play in:

What are your goals (how much space are you trying to heat, and to what degree)? Each system has a different capacity for heating. How much control do you want to have? (Some systems are active, and some are passive. (i.e. You can crank up a rocket mass heater, but there’s not much you can do to change water barrels).

What constraints are you already working with? (I.e. difficult/rocky soils will rule out an underground heat-exchanger.) Think about how much floor space in the greenhouse you have for things like water barrels. And most importantly think about the time and labour involved in installing each system, as well as the on-going time/labour that it can take to run each system (i.e. an underground heat exchanger can be automated, whereas a rocket mass heater cannot be). Again, while you need to do some homework upfront, having a warm greenhouse churning out fresh food throughout the winter (and for free!) is the best payoff you can get.

Year-Round Greenhouse Planting Calendar
By Kylie Gettleman
How do you keep your backyard greenhouse supplying food year-round? There are two fundamental factors to consider when planning your greenhouse planting schedule: temperature and day-length.

Day length is arguably the most important factor when determining when to plant in your greenhouse. If you are not using supplemental lighting, then it will be critical for you to know what average day lengths are for your area throughout the year. Where we’re located in Colorado, early February marks the time when our day length begins to reach 10 hours per day, which is generally enough daylight for seedlings to grow. And mid-November marks the time when our days drop below 10 hours and plant growth significantly slows. Plants will continue to survive throughout the winter, but will typically enter a semi-hibernation. If you plant your winter garden early enough, plants will be nearing maturity by the end of November, and you’ll be able to slowly harvest all winter long from the semi-dormant plants, even without supplemental lights.

The temperature inside your greenhouse and the multiple micro-climates within will also affect growth. The coldest parts of your greenhouse will typically be close to your greenhouse glazing and right next to your vents. That’s where you’ll want to place your cold hardy vegetables throughout the winter, like spinach and kale. The warmest part of your greenhouse will typically be along the north wall where the sun reflects off and hits the plants in that vicinity. By planning your planting schedule according to day length, managing your plant’s location based on temperature, and choosing the right crops and varieties, you’ll be able to harvest year-round vegetables.

Here is a rough planting calendar that we use for our location near Denver, Colorado at about 40 degrees latitude.

February:

The days are beginning to lengthen as we move towards the equinox. Where we’re located in Colorado, February marks the time when there is now enough daylight (about 10 hours a day) to start to seed new crops without needing to use supplemental lighting.

Begin seeding your first spring round of cold-tolerant crops (lettuce, kale, radishes, beets, carrots, peas, etc.).

Begin seeding warm-loving, long season vegetable crops in the greenhouse (tomatoes, peppers, eggplant, etc.). These crops typically take 100-150 days to mature, and they do not tolerate cold weather, so plan to give them the longest possible time in a warm growing environment while they grow and ripen their fruit. You can start these crops in your greenhouse and transplant them outside once the nighttime temperatures are consistently above 55 degrees. Or you can keep them growing in your greenhouse all summer long and into the fall.
March/April:

Near the spring equinox, daylight lengthens, and plants begin to grow more quickly in the greenhouse. Begin to seed warm season crops with shorter days to maturity (beans, basil, cucumbers, squash).

Begin to harvest from your first round of cold-tolerant crops and continue planting cold tolerant, quickly growing crops to replace them.

May:

The lengthening days and warmer nights allow for much faster growth in your greenhouse.

You’ll likely be harvesting a lot from crops like lettuce, kale, spinach, and peas.

If you have started transplants in the greenhouse, you can now start to plant cold tolerant transplants outside (broccoli, cauliflower, cabbage) once the nighttime temperatures are consistently above 45 degrees and warm-season transplants outside (tomatoes, peppers, eggplant) once the nighttime temperatures are consistently above 55 degrees.

June/July:

This is generally a hot time for greenhouses, depending on what type of cooling systems you have. Your warm crops, like peppers, eggplant, beans, and tomatoes will be very happy in the greenhouse, but you’ll still have to watch for overheating and make sure you have proper ventilation and that you have enough humidity to keep the plants from transpiring too much and wilting. (To learn more about the relationship between temperature and humidity in your greenhouse, see our blog post about VPD).

August/September:

August and September is usually the time to start to plant your winter garden. November thru January, day length shortens such that plants will grow very slowly without supplemental lighting. Your goal with a winter garden is to plant early enough that most plants are close to reaching maturity by November or December. As plant growth slows, your crops will go into a semi “hibernation,” and you will be able to harvest slowly throughout the winter even without seeing very much new growth.

Before the first frost in your area is also the time to move some potted plants inside the greenhouse for the winter. Citrus, figs, peppers and tomatoes that are in pots outside can survive the winter in pots in the greenhouse. We’ve seen potted pepper plants that are over three years old grown this way, and are still producing fruit.
October:

Days are beginning to shorten. You’ve already gotten your winter garden planted, but October can still provide enough light to start very short cycle crops (like radishes that only take 20-30 days to mature) or to start crops that you plan to harvest in the late winter/early spring, knowing they will grow very slowly throughout the winter.

Hardy vegetables like spinach, lettuce, and kale planted now will typically have time to germinate and become small plants, overwinter, and grow rapidly as days lengthen in February. Winter and early spring vegetables taste sweeter than at other times of the year as vegetables begin to store sugars in their cell walls to protect against frost damage.

November/December/January:

A time of rest and dormancy before the next season begins again. You can continue to harvest slowly from those plants that are mature, pulling off kale leaves, digging carrots and beets, or cutting spinach. Now is also the time for winter pruning your fruit trees, reading seed catalogues, and planning next year’s garden.

If you do choose to use supplemental lighting, then greenhouse growth does not need to slow down during this time. Leafy greens and root vegetables will thrive in your winter greenhouse with a little added light. We’ve also seen winter greenhouses grow warm weather crops, like tomatoes and peppers, with supplemental lighting if the nighttime greenhouse temperatures can stay at least above 62 degrees. Because a Ceres greenhouse harvests light through reflecting off of its north, east and west walls, we can use less supplemental lighting for strong winter growth.

For more information:

https://geodesic-greenhouse-kits.com/good-advice-on-the-growing-dome-planting-schedule/


https://www.maximumyield.com/definition/143/calcium-ca
https://www.maximumyield.com/bone-meal-basics/2/1310

https://nevegetable.org/vegetable-transplant-production

Yes.

The more difficult question lies in the specifics. How big does my greenhouse need to be? What do I plant? What growing method do I use? How do I design the space? What kind of greenhouse will I need? These are the questions you need to consider if you and your family are trying to be more self-sufficient. So let’s address each one.

**How big does my greenhouse need to be?**

This question can lead to a whole host of new questions, such as how many vegetables does your family eat? And how efficient is your greenhouse? So keep in mind we can only approximate. A 12 ’x 18’ or 12’ x 24’ can be the appropriate size if the family is growing fairly intensively. An 18’ x 24’ might be more ideal if you want to include fruit trees because they take up more space. Around 400 sq ft (20’ x 20’) is what we would recommend to eliminate the need for the grocery store.

**What do I need to plant?**

This question is really about personal preferences. So, the answer comes down to– what do I want to eat? But also, what am I capable of growing? Climate will also play a factor in what you might want to plant. There are plenty of resources that can help guide your planting, and we recommend using one of our professionals to help answer any questions related to planning your grow calendar.
**What growing method do I need to use?**

We recommend using soil if you are a novice or are on a budget. But, if you are trying to grow intensively and space is a factor, you might want to consider hydroponics. If you are an experienced grower, who wants high-output and a closed-loop growing system you might want to consider [aquaponics](#) (which incorporates the use of fish into the system as a means of fertilization and recycling of organic matter). We design for all systems and believe in the virtue of each. For a residential greenhouse any system can be used, and we can make recommendations considering factors such as how large of a greenhouse you have (soil takes up more room, as do fish tanks), how much you are willing to spend (nutrients for hydroponics can be pricey), and what you want to grow ([hydroponic systems](#) are great for leafy greens and tomatoes, but will not work for root vegetables).

Here is what you could expect (approximately) from an 18×24 **aquaponics** system:

- **75-100** heads of LETTUCE or LEAFY GREENS weekly
- **150-200** lbs. of FISH annually
- **225** lbs. of TOMATOES annually
- **135** MICROGREEN flats annually

Would this be sufficient to feed your family? If you love lettuce and tomatoes, then everyone will be plenty satisfied. But a system like this does not allow for much plant diversity.

A soil based system typically allows for the most plant diversity since you will be able to grow root vegetables, leafy greens, fruiting crops, herbs, and trees all in one space. Companion planting many different varieties together can also help increase plant health and reduce pest and disease pressure.

The choice is up to you.

**How do I design the space?**

This will depend on what you are growing and whether you are using any additional climate controls. If microgreens are at the top of your list, you can design your system with shelves and supplemental lighting. If you want fruit trees, then you will have to consider maximum height growth and shading. We can work together to lay out the space that makes the most sense for your output and taste preferences.
What kind of greenhouse will I need?

If you desire a year-round grow system, we recommend a Ceres greenhouse. Ceres’ greenhouses are passive solar and highly insulated, built from quality long lasting materials. This means you can expect to save money on operating costs, energy bills, and replacing materials. A Ceres greenhouse uses 50% less energy than a traditional greenhouse and can capture 50%-100% more light. If efficiency and longevity are priorities, opt for the best in the industry.

Top 3 Greenhouse Pests and How to Deal with Them
by Haley Bridgnell

Pests can affect greenhouses a little differently than the outdoor garden, particularly year-round insulated greenhouses that are warmer and more humid. The top three pests we’ve encountered in our years of greenhouse growing are aphids, fungus gnats and white flies. Of course, is not an exhaustive list —you may encounter many more in your experience — but these three are by far the most common in year-round residential greenhouses. We always recommend natural strategies first, like prevention and beneficial insects in managing these common insects; however, we’ll also discuss some natural sprays below.

Aphids

Quick facts:

- Reproduce prolifically and very quickly
- Easily spotted as oval gold shapes on the underside of leaves
Aphids are usually the number one insect problem in greenhouses. You can easily identify them as gold oval shapes, usually in clusters, on the underside of leaves. The thing to understand with aphids is how quickly the population can take off: Reproduction occurs without actually mating, and only females are produced. Females reproduce within a week, creating 3-10 offspring per day, which again, start to reproduce prolifically within a week. In short, aphids can go from a small problem to a big problem very fast.

**Tips and tricks for dealing with aphids.**

It sounds a bit cliché, but the easiest solution to aphids is to catch the problem early before it takes over. It’s important to regularly look under leaves and being attentive to your greenhouse. If a population gets hold while you’re on a three-week vacation, it could very easily destroy your plants.

If aphids do establish in your greenhouse, we’ve found one of the most effective techniques for removing them is the simplest: water. You can simply wash these leaf dwellers off with a hose or spray bottle. This disturbs them enough, so they do not establish or stick around. The downside here is it requires a good eye and some time: aphids will reside on the shady underside of leaves, so you have to turn leaves over and gently spray each leaf. Again a hose on a gentle spray works for larger areas; a spray bottle works for targeted areas or leaves heavily populated. You want to make sure you keep a gentle spray, so you don’t bruise the leaf too much in this process. You can see the before and after effect of washing off a kale leaf to the right.

Some leaves may be beyond rescue, in which case remove these if it won’t severely damage the plant. We recommend washing off leaves once every other day until you see pest populations severely diminishes. Below you can see aphids on a kale leaf, and the same leaf after it has been washed off.

Also keep in mind that aphids can persist through the winter, and in many, they’ll produce wings and migrate to other parts of your garden… all part of the fun in keeping these pests at bay.

In combination with washing aphids off, you can also use beneficial insects – ladybugs and lacewings – to combat the problem. Usually, naturally occurring concentrations of ladybugs are not enough to combat a full aphid outbreak, but they can be a great supplementary defence and a protective measure to keep aphids at bay over the long term. You can attract them to your greenhouse (if it is kept open) by planting pollinating flowers which they eat in addition to insects.

For larger outbreaks, you can also purchase ladybugs or lacewings at a garden store or online. We go into more tips for using beneficial insects in your greenhouse in our next blog.
In all our strategies, a very important tool is identifying what you’re seeing, so you can find the right control measure and don’t accidentally kill a beneficial insect. For instance, young ladybugs look like tiny alligators (shown below), and could easily be confused for a harmful insect. However, these maturing ladybugs consume much more aphids than the adults, so make sure you keep them around.

Gnats

Quick facts:

- Lay eggs in the top layer of soil if the soil is wet
- Combatted by reducing moisture on the soil, or sticky traps
The second major problem insect is fungus gnats. These lay eggs and pupate in the top layer of soil. When they hatch they develop wings, turning into annoying flies that look much like your household fruit fly (though gnats are a slightly different variety). People are often familiar with these as they usually are common with house plants. They feed off dead plant tissue, and also leaves, particularly seedlings.

Because they’re soil dwellers, the best strategies for controlling gnats are covering the top layer of wet soil with something that they can’t hatch in, like pebbles. We also like to use self-watering planters, like Farm Tub’s, which water roots from a reservoir at the bottom of the planter, allowing the topsoil to stay dry.

With flying insects like gnats, you can also hang sticky traps to catch them. I find that when a population emerges, they tend to collect on windows and sills. You can wipe out a large number just by spraying them off with a window cleaner or using a vacuum to suck up hundreds or thousands at a time. As with all pests, you want to use a combination of controls, like a vacuum and sticky traps, to knock the population out over time. There are parasitic mites and nematodes that will eat fungus gnats, but ordering those as specialty items is usually above and beyond what most gardeners want to do.

**Whiteflies**

It’s a little harder to give the prize for third most problematic greenhouse pest since, beyond aphids and gnats, several can be a problem, though not as severe. In our years of experience with year-round greenhouses at Ceres, whiteflies probably come up as the next biggest issue. These are similar to gnats, though white, and can also be combatted using sticky traps.

We’ve also commonly seen rolly polly (pill bugs), which emerge on wet soil and can also eat seedlings. Greenhouses, particularly energy-efficient greenhouses, trap moisture more easily. That’s nice as it reduces the watering requirement, but can often lead to wet soil.
Thus, we recommend being careful not to overwater the greenhouse. This is another nice time to use a self-watering planter, like Farm Tubs or another design, to keep the soil surface dry, while still allowing the plant roots to access water in the reservoir.

**Natural sprays**

If the above methods are not getting the job done, there are also some more earth-friendly insecticidal sprays. These typically use pyrethrum – a naturally occurring plant chemical (made from chrysanthemums) that is toxic to insects. The advantage with sprays is that you have much higher effectiveness at killing pests compared to just washing bugs off. Pyrethrum or other natural insecticides will kill adults, larvae and eggs. The disadvantage is that they are expensive, and require just as much time to use as simple water washing. Greenhouses using aquaponics should be careful about which sprays to use: pyrethrum can be harmful to fish.

**Pest Prevention**

There are different mantras on how to reduce the number of pests that get into your greenhouse in the first place. Some people take the ‘controlled environment’ approach, preventing bugs from getting into the greenhouse by controlling what gets in. That means washing off any starts brought in, using screens on the windows and openings, not letting pets in, even changing shoes at the door. This can make sense if you have a commercial greenhouse where an infestation can mean a big financial hit.

At Ceres, our attitude is a little different. Keeping the greenhouse completely controlled and shut off from the outdoor environment takes a lot of effort and is not always successful. We recommend taking the easy measures like washing off starts before they’re brought into the greenhouse. But sweating every move, and everything that comes in usually takes the fun out of growing. Even with those measures we’ve found the bad bugs simply find their way in one way or another. Rather, we focus on creating a balanced healthy ecosystem in the greenhouse that is capable of defending itself and recuperating quickly.

This means focusing on overall plant health and a greenhouse environment that mimics the best of outdoor conditions. Healthier plants are much better equipped to tolerate and defend against insects. Thus, ensuring your plants are healthy by maintaining good soils and nutrients, minimizing temperature shocks with proper energy-efficient greenhouse design is the first defence against insects. During colder months, they are much more humid and do not have as much air movement since the greenhouse is usually closed (not ventilated). Stagnant, humid air is a perfect home for breeding insects. A couple of tips to accommodate:

- Keep up air movement. This makes it much harder for pest populations to establish. It also strengthens plants if they are gently moving. We recommend a circulating fan positioned in a corner of the greenhouse, creating some circular air movement.
- Do not overwater. Too much humidity and wet topsoil increase insect breeding.

What is your experience with insects in or out of a greenhouse? Let us know by emailing us at info@ceresgs.com.

https://www.youtube.com/watch?v=9QSxQhxJAVQ

https://www.youtube.com/watch?v=o2NtBCS2_WQ