**Greenhouse Comparison**

|  |  |  |  |
| --- | --- | --- | --- |
| Greenhouse | Description | Pros | Cons |
| A-Frame (stand-alone)  $25 per sq. ft | Singular triangular A-frame with glass or translucent poly-carbonate glazing. Build South facing. Ideal location: open field/backyard | * Snow slides off roof without causing damage * Simplicity of design * Less material used compared to other designs | * Air circulation not ideal because of corners * Narrowing side walls limits functional use * Air circulation problematic in corners * Not conducive to heating throughout winter |
| Gothic Arch (stand-alone)  $25 pr sq. ft | Walls bent over frame to create a pointed roof. Eliminates need for structural trusses with plastic sheeting for glazing. Ideal location: Open field/backyard, south facing | * Ideal for shedding snow and rain * Less material used compared to other designs * Simplicity * Plastic sheet glazing reduces design cost and conserves heat | * Low side wall limits growth space and headroom * Not conducive to heating throughout winter |
| Lean-to / attached  $10-25 per sq. ft | Shares the wall of another structure. Build south facing | * Costs less than stand-alone greenhouse | * Temperature difficult to regulate |
| Geodesic Dome (stand-alone)  $33 per sq. ft | A dome with a triangular paneled frame made with polycarbonate or glass | * Structural strength * Greatest snow load capabilities * Max use of sunlight * Aesthetics * Growing can happen all year round * Stable in wind and snow * Good gathering place * Similar to passive solar greenhouse | * Complex to build * Expensive if using glass * Heat retention * Needs lots of ventilation * Limits head room * Needs a foundation |
| Hoop (Quonset design) (High tunnel)  $5-10 per sq. ft | Common in commercial operations. Bent aluminum or PVC tubing to form an arch, usually covered in plastic sheeting. Ideal location: open field/backyard, south-facing | * Inexpensive and easy to construct * Snow and water slide off roof * Flexibility in sizing, small or large structure, can easily make structure longer * Provides good sunlight * Ergonomics * Lots of space for plants * Easy to get good ventilation | * Not as sturdy as A-frame * Glazing needs to be replaced every four years * Low insulation, higher heating costs * May need a blower to keep the glazing inflated * Glazing can be damaged by severe weather or heavy snow mass * Not conducive to heating throughout winter |
| Pit  $6-$12 per sq. ft | Greenhouse roof over a hole in the ground framed with cement walls. Better option in places with extreme heat and little to no snow. Can use passive solar technologies/Chinese style | * Always stays about 10 degrees warmer than an above-ground greenhouse * Fits with verge passive solar * Makes use of natural cooling | * Receives poor natural light in the morning and evening * Easy to damage because the roof is at ground level |
| Barn-style (stand-alone)  $25 per sq. ft | Ground-level vents to improve air circulation. Used in places with hot summer months | * Sturdy and strong roof * Lots of headroom |  |
| Passive Solar (lean-to)  $20-30 thousand (Marty and Melanie)  $65-70 thousand (Rob Avis estimate with builder)  $30-40 thousands (Rob Avis estimate of materials)  $25,000 (Carson’s estimate) | Similar to Chinese style. Lean-to style. Attaches directly to the side of another structure. Utilizes one solid wall to retain heat. | * Integrated design possibility * Snow slides off roof * Best thermal performance * Good gathering place * Good design for hobby greenhouses | * Not good for larger operations * Expensive * Likely to only receive midday sun * Heating components (barrels of water, straw bales, etc.) take up growing space |
| Chinese Style  $30,000 | Similar to passive solar. Structure always faces south. Has 3 supported walls. Only south side is transparent material. Solid north wall maintains consistent temperature and provides strength. Made from materials 30+ inches thick. South wall is arch shaped to absorb heat from the sun. Straw, soil, or cement insulation pads used on south side wall to hold heat. | * Energy efficient * Productivity higher than high-tunnel style * Work towards goal of reducing energy costs * Permanent structure * Strong building van withstand snow and wind * Can be heated * Retractable energy curtain saves energy | * No proven commercially viable models available * Expensive * Productivity lower than gutter-connected greenhouses * Reduced yields and product quality due to irregular shape causing lack of uniformity in plant growth * Inefficient land use * Blocks morning and evening sun |
| Conventional (stand-alone)  $25 per sq. ft | Cabin shaped frame typically with glass or poly-carbonate glazing. Ideal location: open filed/backyard, south facing | * Strong Structure * Long side walls maximize space for growing * Durable, long term option * Can connect multiple structures together * Excellent lighting * Room to add vents or windows * More efficient air circulation | * Needs an anchored base because it is top-heavy * Expensive to heat * High initial construction costs * Requires a foundation * Requires more material than other designs |
| Shipping Container  $15,000 | Refurbished metal shipping container | * Easy to ship * Compact and contained * Cheap and available * Best for lettuce | * Environmental control difficult * Poor structural integrity of used containers * High operational cost * Need high intensity lighting (increases heat and humidity) * Difficult to ventilate * Poor ergonomics * Low comparative output * No natural light * Aesthetics * Not a good gathering place |
| Insulated Plant Factory | Similar to shipping container. High tech | * Potential to reduce energy costs with LED lights | * Not a good gathering place * Costly * May not meet visions for self-sufficiency and re-learning skills |
| High-tunnel style | Unheated made of single covered poly on steel hoop structure. Most widely used greenhouse around the globe. | * Simplest and cheapest option * Operating costs are low * Low energy requirement * Simple technology, low cost for tooling and training * Low-cost products * Wide variety of products * Opportunity for greater community involvement * Can be moveable | * Short growing season * Low yields/revenue * Low quality products * Dependency on soil * Low profile * Low strength, to support the weight of tall crops * Must be reglazed every year to prevent collapse due to snow * All-year growing not possible |
| Stand-alone | Double poly covering on engineered steel structure. Glass can also be used. Insulated with blown air between the layers. Forms much of the small-scale greenhouse industry in Canada. Can have soil-based production with little or no environmental controls or a high-tech facility with soilless production, grow lights, and full environmental control suitable for year-round production | * Good starting place for commercial greenhouse production * Can be low, medium, or high tech * Pros depend on technology employed | * More expensive than high tunnel * Can do anything but wont necessarily be the most efficient * Less energy efficient than gutter-connected * Cons depend on technology employed |
| Gutter-connected | Norm for commercial production in Canada. High tech. Can range in size from small to large. | * Highly productive * Capable of year-round production * Proven technology * Withstand harsh winters | * High skill level required to use * Expensive |

*Elements of Passive Solar*

* Aperture/collector (south facing windows)
* Absorber (hard and dark surface of wall or floor material)
* Thermal Mass (material that retains and stores heat)
* Distribution (circulation of heat through natural conduction, convection, and radiation)
* Control (roof overhangs, blinds, awnings, shade trees)

*Passive Solar Greenhouse Design*

What are the Design Goals?

* Extend growing season
* Gathering place
* Food production
* Need to figure out minimum threshold temperature to create a design

Site Selection

* Need access to lots of sun
* May need to remove some trees

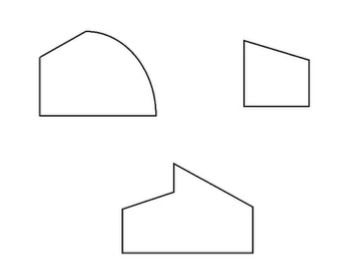
Aspect Ratio

* Width and length of greenhouse
* Minimum of 1:1, ideally 1:2 or 1:3

Orientation to South

* Orient 15 degrees to the east
* Put up next to a forest that will take away some of the late Western sun in the summertime
* Give shade towards end of day to help keep the greenhouse from overheating

Shape

* Based on how people locally construct
* Materials available to you
* Snow load
* Height of greenhouse
* 

Foundation

* Plants very susceptible to disease inside greenhouses so they need access to subsoils (better to grow in the ground than in garden beds)
* Insulated concrete forms - ten-inch piles at 8-foot centres all the way around outside of the greenhouse. Piles create resistance against the pressure of the soil on the outside of greenhouse
* Pick a foundation that allows you to store thermal energy in the soil for later use in the season

Knee wall

* Wall at front of greenhouse
* Snow accumulation here
* Vent wall on top of knee wall (these two things together should be at least as tall as the tallest person using it, so they don’t hit their head)
* Build with ergonomics in mind

Ventilation

* Cannot over ventilate a greenhouse
* 12-20% of southern facing glazing exposed to sun
* High vents, low vents, cross vents
* Heat storage mechanisms
* Put in as much as you can afford to put in
* Overhead garage door to increase airflow
* Add fans to blow air around

Glazing

* At least 70% transmissivity
* Designed for snow load
* Manufacturers
  + Co-ex corp
  + Polygal
  + AC plastics
* Polycarbonate
  + Light diffusion
  + Very expensive
  + 15-year lifespan, 5-7 years before it starts to become discoloured
  + Very expensive to ship
* Solarwrap from Spain
  + Less expensive
  + Better transmissivity
  + Longer lifespan
  + Easy and cheap to transport
  + Flaps in the wind
* Glass
  + Glass will break in hail
  + Very heavy
  + Very expensive

Artificial Light

* May not need to add additional light (only growing 3 seasons)
* Growing four seasons will need additional light
* Most expensive cost of running greenhouse
* Electricity more expensive than gas, coal, wood
* 3 seasons growing seems best

Insulation

* Needs to be resistant to temperature fluctuations and humidity
  + Insulated concrete forms
  + Hempcrete
  + Styrofoam
* What is available to you
* Reduce heat loss by putting thermal curtain under glazing
* Get through winter without fossil fuel with insulated curtain
* Thermal Mass
  + Water tanks
  + Granite
  + Water
  + Rock walls
  + Glass
  + Subterranean heating/cooling systems
    - Earth tubes to keep a root cellar cool

*Traditional Root Cellar*

* Pit Passive Solar greenhouse plus root cellar approximately $20,000 to build
* Traditional Root Cellar
  + Insulated Doors that lead down into the earth
  + Walls are concrete, cinder block, or other materials
  + Make sure roof and walls are well supported to avoid collapse

*Cold Storage*

* Walk in cooler
* 10 x 10
* Using an off the shelf A/C unit
* CoolBot and baseboard heater
* $330.00 for CoolBot
* $6000 - $10000

*Commercial Kitchen*

* $15,000 - $100,000

*Earth Tubes/Climate Battery*

* Approximately $1800 for Rob Avis’ passive solar greenhouse
* ~$3000 12ftx60ft ~$20000. Suppliers in Barrie/Toronto polycarbonate pipes for the earth battery (6-8 weeks for product)
* Insulate the foundation
* Build with perforated pipe
* Backup heater paired with a climate battery in cold climates
* Deeper you dig, better they will perform, but the more it costs
* Incorrect installation can lead to pooling of condensate and mold growth
* Clays and silts have more geothermal heat capacity
* Joints must be air and watertight
* Do not install in areas with a high-water table
* Bury 5-6 feet deep, 8 feet is ideal

*Water*

* Rainwater
  + 50% of nitrogen in ecosystem comes in the form of rainwater
  + Low energy water source
  + Low in minerals

*Additional Information*

There are opportunities to reduce energy costs by tying greenhouses in with district heating systems. Low-tech greenhouse systems (high-tunnel style greenhouses and lower-tech stand-alone greenhouses) can be operated by an experienced greenhouse labourer, or an experienced gardener, who will run the operation and supervise labourers. Larger-scale gutter-connected systems with modern commercial technologies will require a combination of appropriate university training plus relevant industry experience. Smaller-scale versions of higher-tech systems, either gutter-connected or higher-tech stand-alone systems, can be operated by experienced growers with either formal training (diploma or higher) or those with an extensive agricultural background.

In terms of agronomics, almost any crop can be grown in a greenhouse. The real question, however, is which crops can be economically grown to ensure the commercial viability of a greenhouse enterprise.  Tomatoes, cucumbers, peppers and lettuce account for most crops grown in greenhouses, both globally and in Canada, because they produce the most revenue per square meter based on both price and yield. Lettuce is the best greenhouse crop. Fast growing and multi-season. Does not need a lot of space to grow.

Integrating the greenhouse with a market garden. This allows the enterprise to offer a wider range of products including root crops. Bedding plants are also a large and profitable market as some studies have shown them to be more profitable than greenhouse vegetable production.

Framing

|  |  |  |  |
| --- | --- | --- | --- |
| Type | Price | Pros | Cons |
| PVC | $17.41 per tube | * Lightweight * Flexible * Affordable * High heat retention * Durable | * Aesthetics |
| Wood | $1.77 per linear foot | * Long lasting * Can be stained or painted * Durable * Affordable * Cedar is a natural insect repellant | * May rot over time * Warping may occur |
| Steel | $156.89 per piece | * Rust resistant * Durable * Aesthetics | * Expensive |

Glazing

|  |  |  |  |
| --- | --- | --- | --- |
| Type | Price | Pros | Cons |
| Polyethylene film | 188.99 per roll | * Opaque or transparent * Easy to cover greenhouse * Reduced nighttime heat loss * Adequate condensation runoff * Reduced daytime heat gain * Allow sunlight spectrum to pass through * Acceptable light diffusion * Affordable | * Short lifespan * Easily punctured * aesthetics |
| Polycarbonate Sheets / Acrylic Panels | $22.00 per 24” x 48” sheet | * Tough * Resists UV damage * Resists heat and cold * Stands up to snow and rain * Rigid * Double wall for added insulation | * Low impact resistance * Expensive * Polycarbonate becomes discoloured over time * Could develop mold |
| Corrugated Fiberglass Sheets | $34.50/26” x 96” sheet | * Clear or translucent * Lasts for 10 years without yellowing or cracking * Stands up to snow and rain * Rigid | * Not environmentally friendly * Scratches easily |
| Glass (3/16 or ¼ inch thick)  \*\* Glass house and double-poly houses likely top two contenders for Canada for stand-alone and gutter-connected greenhouses | $5.78/sq. ft annealed  $8.44/sq. ft tempered | * Lasts for 30 years * High transparency * Stands up to snow and rain * Aesthetics * Rigid * Likely to trap less snow on the roof * Use of high impact tempered glass * Can use shade of energy curtain to reduce energy costs * Diffuse glass to reduce direct radiation | * Expensive * Poor insulation * High retention of heat in summer * High levels of direct light * Needs to be cleaned * Could break if stressed |
| Double-inflated polyethylene film |  | * Lower cost of construction * Resistant to hailstorms * Energy savings * Lower air temps achieved during summer * Can be installed on stand-alone greenhouses with no special training * Diffuses light * Easy to use on simple high-tunnel greenhouses | * Specialized installation required when installing on gutter connected greenhouses * Changed every 3-5 years * Can be ripped easily |

\*Will need heat and artificial light sources to grow throughout the winter in all greenhouse styles\*

\*Insulation and ventilation are key design components\*

Equipment required for winter growing

* Heating
* Artificial lighting
* Single- or double-layer thermal screens
* Double layer polyethylene film
* Heating system at plants level

Case Studies

**All year-round Chinese style passive solar pit greenhouse in Nebraska using Climate Battery**

* 26-year-old greenhouse in Nebraska. Heated solely using geothermal technology (climate battery)
* 17 6-inch tubes, 8 feet deep, 230 feet of tube
* Blower to blow air around
* Reflection wall
* No glazing on north only on south and top, polycarbonate glazing 3/8 inch thick
* Galvanized metal walls, ¾ walls
* Floor dug four feet below ground
* Roof slanted to catch southern sun
* $25,000 to build without labour costs
* Averages 80 cents USD or $1.02 CAN per day year-round for energy
* Grows warm weather produce in the snow – citrus, figs, pomegranates
* Second version has a pond (hydroponics)

**Le Jardin des Funambules**

* Gothic Arch with insulated foundation
* $25-30 thousand to build
* Investment of knowledge to grow
* Rocks with French drain around greenhouse
* 32 x 100 ft, 35 x 100 ft, 35 x 105 ft
* Make most money on cherry tomatoes
* Accessibility to farm, greenhouses, and inside the greenhouse super important
* Grow ginger for $40/kilo
* Bring in beneficial insects
* May through October do not need to heat with propane

**Lida Farms Deep Winter Greenhouse/Root Cellar**

* Located in Northern Minnesota
* Passive-solar design with solar panels
* Growing cold-tolerant greens
* Storage crops stored in an attached root cellar
* Small cottage provides back wall for greenhouse
* Hillside topography to provide more constant temperatures
* Building well below the frostline
* Greenhouse stands 16 feet tall
* Four feet below grade have an insulated foundation with tiling and rock for a solar air heat sink and the radiant floor tubing connected to the solar panels
* Ties into existing infrastructure with an outdoor wood boiler for back up heat source
* 32 x 16 feet
* Double-walled polycarbonate (retains more heat than plastics)
* Root cellar 9 x 14 feet beside the greenhouse
* Made with simple timber construction
* Using evacuated solar thermal tubes for heat
* Costs
  + Greenhouse
    - Excavating: $1841 USD
    - Labour: $1330 USD
    - Plumbing: $1837 USD
    - Materials: $4273 USD
    - Lumber: $7589 USD
    - Solar: $7057 USD
    - Total: $23,928 USD or $30,494.44 CAN
  + Root Cellar
    - Excavating: $789 USD
    - Labour: $570 USD
    - Materials: $649 USD
    - Lumber: $2710 USD
    - Total: 4,719 USD or $6014.01 CAN
  + Propane in the winter: An average of $300 USD or $382 CAN

**Rob Avis Passive Solar**

Designed and built two Passive Solar Greenhouses in Alberta, one with a climate battery

“What Rob Avis Did Wrong”

* Glazing angle perpendicular to angle of sun in the month you want to grow in
* Polycarbonate – angle to use is function of snow load
* Vents were too close to the ground, need a knee wall
* Used a concrete foundation, means growing in raised beds
  + Plants do not have access to subsoil in raised beds
  + Difficult to put enough nutrients into raised beds
* Not enough top vents
  + Low air flow = more disease
  + Automatic openers
* Rocket Mass Heater
  + Difficult to keep fueled, need to continually add wood to them
* Most energy intensive component of a greenhouse is artificial lighting, so he does not grow after January 15th due to lack of light
* High nutrient density soil essential in a greenhouse
* Need to know minimum threshold temperature, this depends on the type of plants you are growing
* To stay above zero, you need an automatic heating system
* Need fans to more air and reduce temperature

“What Rob Avis Did Right”

* Ventilation
  + Vent wall consisting of low and high vents
* Insulation
  + Standard pink
  + Plastic vapour barrier
  + Sheet metal on outside
  + Side walls are white sheet metal for reflecting
* Knee Wall
  + Where the snow will accumulate, place low vents on top of knee wall
* 12% glazing, 90% of heating comes from this
* Rainwater harvesting
  + Free fertilizer
  + Bison pumps to pump rainwater that is just below the surface of the ground
* Plant pollination crops at front of greenhouse in front of vent wall so pollinators will go into the greenhouse
* Problems in greenhouses
  + Pollination, spraying fish emulation to attract pollinators
  + Not having enough air flow
    - Need cross ventilation with windows and door
* Overhead insulated garage door
  + Provides easier access for heavier work
* Foundation
  + Insulated concrete forms down four feet from soil level
* Structure cost
  + $65-70 thousand with construction
  + $30-40 thousand for just materials
* Heat storage
  + Climate batteries
    - Store thermal energies, diurnal system
* Solar Air Collector
  + Soffit – sheet metal with perforations to allow air flow
  + Used as solar air collector
* Energy stored in fall keeps greenhouse warm in winter

Resources

**Greenhouse Comparisons**

<https://www.fixr.com/costs/build-greenhouse#types-style>

<https://davesgarden.com/guides/articles/types-of-greenhouses-and-which-works-best-for-you>

[https://docs.google.com/document/d/1bYM\_vkqWCuZy1rCbv5d5raEfFiEV-5RxdoGTFE4sSRo/edit#](https://docs.google.com/document/d/1bYM_vkqWCuZy1rCbv5d5raEfFiEV-5RxdoGTFE4sSRo/edit)

https://greenhousefanatics.com/types-greenhouse-structures/

**Greenhouse heated exclusively with solar panels**

<https://www.pv-magazine.com/2020/12/08/solar-greenhouse-for-crops/?utm_source=dlvr.it&utm_medium=facebook&fbclid=IwAR1wc0Ks9hJkVnK5LmNGOPMVfj5NsGtyMfeDdE6VoYkq6SNHRSQMKDTMc1Y>

**Root Cellar**

<http://www.deeprootsfoodhub.ca/community-root-cellar.html>

<https://morningchores.com/root-cellars/>

<https://commonsensehome.com/root-cellars-101/>

**Walk-In Cooler**

https://agriculture.sc.gov/wp-content/uploads/2017/08/How-to-Build-a-Walk-In-Cooler-for-Your-Small-Farm-3.17.pdf

**Shipping Container**

<https://medium.com/@MarkCrumpacker/a-look-at-the-benefits-and-drawbacks-of-container-farms-ea6b949e8a03>

**Greenhouse in Quebec**

<http://lejardindesfunambules.com/>

**Passive Solar Greenhouse with Root Cellar and Commercial Kitchen**

<https://medium.com/@rob_74123/a-greenhouse-for-the-future-combining-a-root-cellar-commercial-kitchen-passive-solar-greenhouse-af5fbaaa0949>

**Passive Solar Greenhouse with Root Cellar**

<https://www.kickstarter.com/projects/1512981845/lida-farm-deep-winter-greenhouse-and-root-cellar-p>

<https://practicalfarmers.org/wp-content/uploads/2019/04/Ryan-Pesch-Deep-Winter-Greenhouse.pdf>

https://www.researchgate.net/publication/280882501\_Winter\_Greenhouse\_Enterprise\_Analysis

**Earth Tubes/Climate Battery**

<https://www.nrcan.gc.ca/simply-science/20319>

<http://www.ecosystems-design.com/climate-batteries.html>

<https://www.greenbuildingadvisor.com/article/my-earth-tube-story>

**Passive Solar Requirements**

<https://passivehouse.com/02_informations/02_passive-house-requirements/02_passive-house-requirements.htm>

<https://bradford.missouri.edu/passive-solar-greenhouse/>

<https://www.teachengineering.org/lessons/view/cub_housing_lesson05>

https://medium.com/@rob\_74123/7-tips-for-passive-solar-greenhouse-design-bd29f8a6bcf0

**Verge Permaculture**

<https://vergepermaculture.ca/2018/11/08/designing-your-passive-solar-greenhouse-part-1/>

https://vergepermaculture.ca/passive-solar-greenhouse/

**Greenhouse in the Snow (Nebraska Greenhouse)**

<https://greenhouseinthesnow.com/>

<https://faircompanies.com/videos/nebraska-retiree-uses-earthss-heat-to-grow-oranges-in-snow/>

**Passive Solar Pros and Cons**

<https://www.ny-engineers.com/blog/green-building-trends-pros-cons-of-passive-house-construction>

**To Build**

<https://umn.qualtrics.com/CP/File.php?F=F_78JCrtZBH8ALDgh>

<https://extension.umn.edu/growing-systems/deep-winter-greenhouses#design-and-construction-2066621>

https://practicalfarmers.org/wp-content/uploads/2019/04/Ryan-Pesch-Deep-Winter-Greenhouse.pdf

Video Resources

**Rob Avis and Le Jardin des Funambules**

<https://fromthefield.tv/catalog>

**All year-round Chinese style passive solar pit Greenhouse in Nebraska using Climate Battery**

<https://www.youtube.com/watch?v=ZD_3_gsgsnk>

**Trail Break Farms Chinese Style Passive Solar using Geothermal Energy**

<https://www.youtube.com/watch?v=KjqkqAixBjk>