# Greenhouses and Environmental Controls

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## Course Topics

- Planning for your Greenhouse
- Business and Regulatory Considerations
- Location Considerations
- Types of Greenhouses
- Materials and Construction
- Interior and Exterior Planning
- Environmental Systems

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## What is Controlled Environment Agriculture?

- CEA is defined as an integrated science and engineering based approach to establish the most favorable environmental conditions for plant productivity while optimizing resources including water, energy, space, capital and labor, and thereby to provide the desired plant product or biological processes under controlled conditions

**University of Arizona, Controlled Environment Agriculture Center*

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## Planning for your Greenhouse

- What are your goals and objectives for growing in your greenhouse? – (for profit, research, food security…)
- What kinds of crops do you intend to grow?
- How much space do you need?
- What is your budget?
- Is this for year-round growing or season extension?
- Will this be a freestanding or attached greenhouse?
- What other functions do you see happening in the greenhouse?

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## Business Considerations

- Ownership, Leasing, or Partnerships
- Relative cost of land and building
- Business growth and expansion
- Customer types and accessibility
- Zoning, Regulations, Licensing
- Entitlement Process
- Permitting, Inspections and Occupancy

Does the location fulfill the business mission?

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## Ownership, Leasing, or Partnerships

- Owning a greenhouse will require capital to purchase, equip and maintain. You'll have control of the use, but responsibility for all of the expenses.
- Leasing can allow you to get started sooner with a lower cash outlay, but there may be restrictions on use and difficulty with improvements if needed.
- Sharing space with other entities like non-profits, other growers or educators can be a way to establish your business while reducing costs.
- Consider partnerships with universities, churches, or non-profits to help with space, financing or operations

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## Land and Building Considerations

- Land and construction costs closest to consumers usually in urban areas will cost more than rural property.
- Consider your primary customer base, business objectives and distribution plan to determine the best location
- Building codes in rural areas may be more adapted towards greenhouse construction than urban locations
- Land zoned agriculture usually has the best alignment with greenhouse structures – auxiliary buildings
- "Entitlement" process for land and building approvals

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## Phasing for Growth

- Look for locations that allow for expansion should your business plan allow or require that down the road.
- Many farmers start out with a smaller aquaponic farm to keep their initial investment lower while developing their skills, products and customers.
- When appropriate, adding additional connected greenhouses and increasing production can be a smart business move if you have planned your space for future growth.

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## Retail or Wholesale Customers

- Understanding your customers and how your product will be sold can have a major impact on determining the best location for your greenhouse
- If you intend to have a retail storefront or farmers market, then your location should be convenient and zoned for retail
- If you are a small farm that intends to service restaurants, then a convenient location within close proximity to your major buyers will be important for quick and efficient service
- Larger wholesale greenhouse operations should be positioned in more rural locations where land and space is more affordable. Larger distribution of product can be delivered weekly by trucks.

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## Accessibility Considerations

- Be sure your location is convenient for employees, suppliers, customers and utilities.
- Hosting public events such as classes or farm to table dinners can trigger code requirements for things such as:
  - Number, location and size of parking spaces
  - Restrooms with specific door size and turning radius
  - Fire suppression systems and egress
  - Width, length and slope of ramps, handrail systems, doors
  - (Americans with Disabilities Act) ADA accommodations
- Always check local building codes to determine if your building and use plan is in compliance.
- Your business can be fined or shut down if not.

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## Zoning

- An urban planning method for determine the regulations, business types, permitting requirements and allowances for land use and building structures in that area
- Locally controlled and regulated
- May be very strict or loosely managed
- Zoning for Residential, Commercial, Industrial, Agriculture
- Subdivided into types of each zoning
- Thoroughly research zoning code BEFORE purchasing
- Sometimes “variances” are allowed for “Urban Farming”
- Check for additional regulations from HOAs, PUDs, BPDs
- Check for “Enterprise or Opportunity Zones”

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## Regulations and Licensing

- State, county or city government may impose specific limitations, exemptions or exclusions on the type of business and activities that can be conducted in an area, land or building.
- Thoroughly investigate the legal, real estate, taxation, land use, building use, structural, business and other logistics prior to making a commitment. Often changes or exemptions can be made, but will require documentation, approvals, hearings, legal entitlements and other oversight that could delay startup
- Facilities and uses out of compliance can result in legal action, fines or complete shut down of your business.
- Many residential zoning codes do not allow for food sales to the public from private property, only personal use greenhouse

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## Entitlement

*Approvals necessary before buying a business property*

- Zoning or variance – needs to align with your business
- Environmental review – water, wetlands, drainage, soils, air, vegetation, surface and subsurface minerals, underground issues, animal habitats
- Impact assessment – water and sewer use, noise, traffic, waste, odors, utility consumption, pollution, security issues
- Permitted uses – for type of business licensing
- Utilities hookup/permits – Electric, water, sewer, internet
- Build out plans and document set – Site plan, architectural renderings, drainage, utilities, landscaping,
- Extensive plans reviewed by planning department – city planner, zoning, utilities, fire dept, building dept, etc.
- Building permit(s) – excavation, well, septic, road, electric, plumbing, HVAC, construction

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## Permits

- May/may not be extensive based on local regs and code
- Most locations conform International Building Code (IBC)
- Many states have additional requirements for things like earthquakes, flooding, tornados, snow, wind, etc.
- Site plan orientation, soils report, drainage, entry, exits, fire access, utility locates
- Building plans with weather requirements, loading, foundation, elevation drawings, electrical and plumbing specs – may require engineer “stamp” prior to city review
- May require multiple meetings to gain approval

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## Building Permits, Con’t.

- Permit issued to licensed General Contractor (GC) or homeowner (if you do the work)
- Subcontractors need to be licensed – plumbing, electric
- Building constructed without permits may be difficult to sell in the future, or may have to meet current code to sell
- Insurance companies can deny payouts if the building experiences issues such as a fire (due to faulty electric) if it wasn’t permitted
- City can issue “cease and desist” orders, stopping construction, causing delays and require “deconstruction”

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## Inspections

- Performed by appointed inspector to ensure contractor quality, safety, code compliance and insurability
- Performed at predefined steps in the construction process – excavation, utility locates, footings or foundation, structure, roofing, sheeting, electrical rough, plumbing rough, final(s)
- Checking of issues to be resolved if there are problems
- Only on-site to inspect what they have been called for
- Most construction should not continue until previous inspection completed
- ALL inspections should be completed before installing aquaponic system

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## Occupancy and Operations

- The final approval to begin using the building for your business.
- Usually requires all inspections to be completed
- Allowances can be made for some business functions prior to receiving Occupancy or Operation Approval
- We suggest that this step is completed PRIOR to installing the aquaponic system
- Celebrate a MAJOR milestone in your project
- Move into operational activities and upgrades as needed

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## Location Considerations

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## Location Considerations

- Master Planning
- Orientation
- Soils
- Slope - Drainage
- Accessibility
- Utilities
- Water
- Transportation
- Site Security

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## Master Planning

- Establishes the goals and objectives of a project
- Determines the short and long term benefits and impacts on the people involved, the facilities and the community
- Provides a framework for the property, improvements, landscaping, buildings, accessibility, use, regulations, setbacks and other site and zoning requirements
- Determines preliminary budgets, scopes of work, resources and scenario plans
- Allows for input from key stakeholders to make informed decisions and ensure the plan meets its goals

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## Orientation

- The goal is to maximize sun exposure throughout the day
- Morning sun is desirable to allow the plant photosynthesis to begin early. East side exposure allows for more winter sunlight
- The sun is lower in the sky in winter than summer
- Your location should not be obstructed by tall trees, buildings or other features that could block sunlight
- Late afternoon sun can be intense so some shading may be desirable from deciduous trees such as maple and oak that shed their leaves in the fall.
- Evergreen trees should not in the suns path as they will block sun year round especially when it's needed in the winter
- The north side of structures is not desirable

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## Orientation Rules of Thumb

**Greenhouses Below 40° latitude:**

- Ridges running North-South direction
- Provides better light distribution (moving shadows) across the plant canopy, more important than light transmission optimization

**Greenhouses Above 40° latitude:**

- Ridges of single-span houses running East-West to maximize light intensity and transmission in the greenhouse particularly in the low angle winter months
- Run ridges of multi-span houses North-South for light distribution

**Kacira, 2012 UA CEAC*

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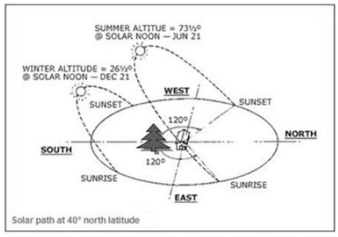
## Sun Exposure

- Programs such as Google Sketchup can be used to illustrate light angles and shading from structures at various times throughout the year.
- For commercial greenhouses a lighting study may be advisable

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## Soils

- Soil testing by a soils engineer is usually required for new building permits and to determine if the soil can properly support the greenhouse foundation
- Locations should have strong soils that do not excessively expand or contract
- Soil engineers can also test for toxins and contaminants like lead, copper or arsenic.
- Recommendations for soil grading, drainage and foundations should be determined in advance of building

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## Drainage

- A site that has a gentle slope to the south increases solar gain and provides drainage of rain and runoff. Look for a fairly level site with a 1% - 2% slope.
- Avoid areas prone to flooding
- For concrete floors install a French drain system.
- Packed gravel or crushed stone floors can allow water to be carried below to the soil. However, gravel floors are hard to clean, can grow weeds or harbor pests.
- A large amount of runoff water from the roof can be collected through gutters and downspouts and be directed to gardens, swales or drainage areas

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## Utilities

- Cost to bring in utilities to the site can be a major expense
- Greenhouse equipment such as large ventilation fan motors typically require 230v single phase or 400v 3-phase power
- Bring in enough power for any future expansion considerations
- Consider the type, availability and cost of fuel sources such as natural gas or propane used for heating

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## Water

- Your greenhouse will require a dedicated water supply from a well or municipal water system.
- Water tests should be conducted to evaluate water quality for heavy metals, contaminants, alkalinity, pH and several other parameters
- Good water quality is important for your farm. Filtration systems may be required to prepare your water for introduction into the aquaponic system

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## Transportation and Parking

- Access for loading and unloading into the greenhouse needs to be planned for
- If you are a large operation working with distributors, you may need to provide access for semi tractor trailers
- Consider employee and customer parking parking
- City regulations may need to provide access for fire department vehicles
- New road construction will have to comply with all local department of transportation building codes

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## Site Security

- Your building and equipment is a significant asset and may need to be protected by exterior fencing and controlled access around the property
- Consider the use of security cameras to monitor around the greenhouse

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## Building Security

- Way to lock the building
- Double entry vestibule ideal to help with biosecurity
  - Keep animals, birds and reptiles out
  - Double doors helps block dust and flying insects
  - Location for footbath, personal belongings storage, hand washing or sanitizing, record keeping, storage space
- Security alarm helpful to discourage intruders
- Security service can call emergency contacts for power outage, intruder detection, or other issues
- Security service can also dispatch emergency personnel

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## Other Considerations

- Avoid areas prone to high winds, flooding, fires
- Zoning codes will dictate building setbacks from roads or property lines, rights of way or property easements.
- Consider your neighbors whether personal or business. How will they be affected by your greenhouse and business? Have you reached out to them?
- If you are intending to run artificial lighting systems, this can have an enormous impact on light levels at night in the surrounding community.

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## Benefits of Greenhouse Growing

Greenhouse structures or Hard lid buildings

- Bio-security controls
- Extended growing seasons, year round
- Protection from elements and outside climate
- Controlled resources usage; water, energy
- Ability to heat or cool
- Pest control and management
- Uses on unproductive land, rooftops or buildings

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## Outdoor Growing

- Works best in tropical climates or long-seasonal growing
- Cover structures used to block rain and as sun shade
- Fish need to be protected from sun, predators
- Controls similar to field crop production
- Challenges with reptiles, birds and animals which can result in pathogen issues

Green Acre Aquaponics, FL

University of the Virgin Islands

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## Selecting a Greenhouse

- Production goals, market size
- Function and Aesthetics
- Climate and environmental conditions
- Plant requirements
- Capital investment
- Cost of operations and resources
- Expected lifetime, depreciation, durability
- Technology, automation, labor requirements
- Supplier confidence, availability and support

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## Attached Greenhouses

- **Advantages of an Attached Greenhouse**
  - Energy efficiency. One wall (usually north) is heated and insulated by the existing structure.
  - Accessibility. Entrance to greenhouse can be from a central head house and provide additional bio security
- **Disadvantages of an Attached Greenhouse**
  - Attaching to an existing building may require additional engineering, costs and cause potential disruptions to the main building

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## Freestanding Greenhouses

- **Advantages of a Freestanding Greenhouse**
  - A wide variety of styles, sizes and prices
  - High light transmission from all sides
  - Can be scalable for future growth
  - Some can be considered temporary structures without the need for a building permit
- **Disadvantages of a Freestanding Greenhouse**
  - Increased heating cost during colder months
  - Need to withstand snow and wind loads

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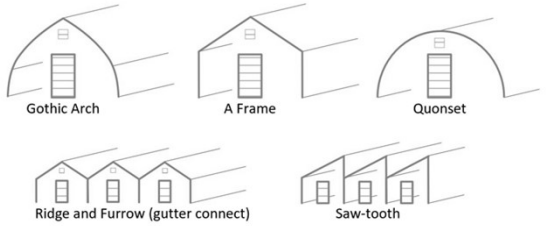
## Common Greenhouse Types

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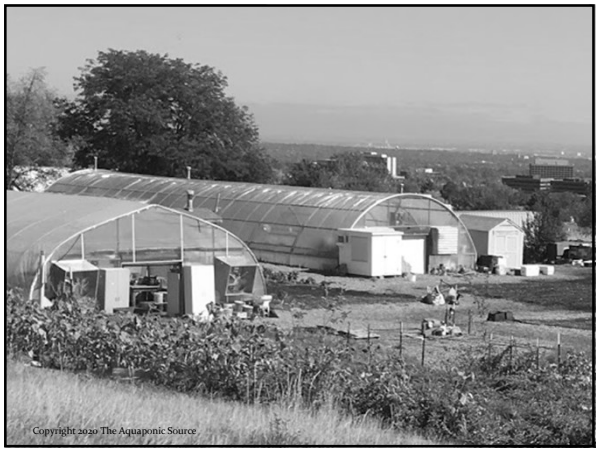


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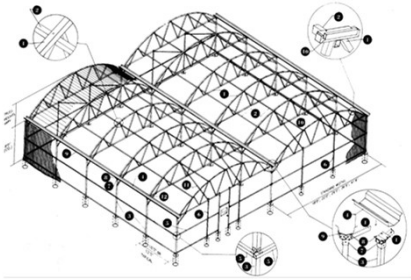
## Gutter Connect Greenhouse



Nexus Teton Quonset Style

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## High Tunnel/Hoop House

- Plastic-covered structures that provide some environmental protection
- May have rollup sides and ends for venting
- Primarily used for season extension
- May not require building permit if considered temporary structure
- Works best in temperate climates
- $1-2/sq ft
- Don't Use PVC for Support pipe!

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## Year Round Greenhouses

- More permanent structures than hoop houses
- Engineered for long term use, wind and snow loads
- Will usually require a building permit
- Will often contain environmental control systems
- Aluminum or galvanized steel frame, concrete footings, rigid plastic, double layer film or glass
- Building Cost ($10.00-$20.00 per sq ft)
- Heating and cooling systems additional
- Installation by manufacturer or contractor

Pardossi et al. 2004

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## Repurposing

- Modifying an existing building by adding glazing and environmental controls can be a great way to utilize a dormant building and save money

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## Passive Solar Greenhouses

- Can use insulation, thermal mass, phase change materials, geothermal, building orientation, roof angle, venting systems and much more to reduce the demand for heating and cooling
- Higher initial building costs offset by lower energy consumption
- Cost $30+ per sq ft
- Great for cold climate

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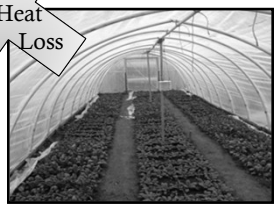
The problem with conventional greenhouses…

Heat Loss



Energy cost ball park: $3-4/SF/ year for heating, cooling and ventilation in typical greenhouse in Colorado.

CERES GREENHOUSE SOLUTIONS

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## Insulation below ground

- Installing insulation around the perimeter of a building between wall insulation and four feet below grade effectively ***couples the structure to deep earth beneath the footprint of the*** structure.
- Equally important, it ***decouples the structure from the surface of the earth immediately*** surrounding the structure, thereby isolating the building from soil whose temperatures vary substantially from season to season.
- In the winter and spring, the temperature at 4 feet under the soil of the research greenhouse averaged 60° F, by August it was over 65° F. The soil outside of the greenhouse at a depth of 4 feet averages 51° F.

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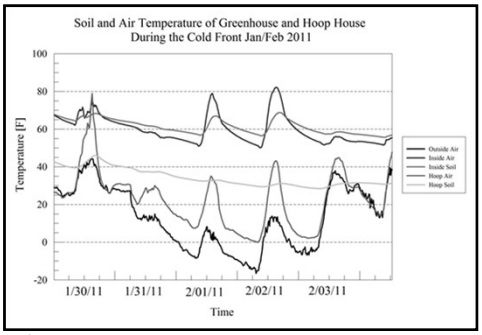
CERES GREENHOUSE SOLUTIONS

## The difference…

Super-insulated, passive solar greenhouse compared to a hoop house
(Neither are conventionally heated. Greenhouse has a GAHT system)

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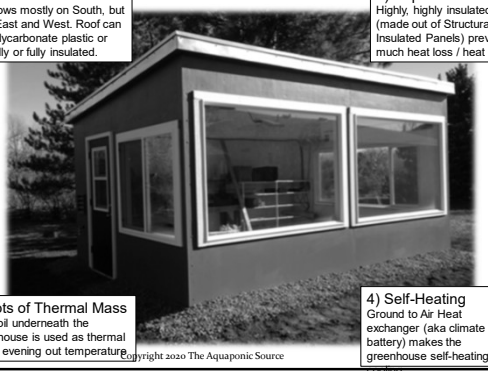
## Key Elements

1) Faces South
Windows mostly on South, but also East and West. Roof can be polycarbonate plastic or partially or fully insulated.

2) Super Insulated
Highly, highly insulated walls (made out of Structurally Insulated Panels) prevent too much heat loss / heat gain



3) Lots of Thermal Mass
The soil underneath the greenhouse is used as thermal mass, evening out temperature

4) Self-Heating
Ground to Air Heat exchanger (aka climate battery) makes the greenhouse self-heating and

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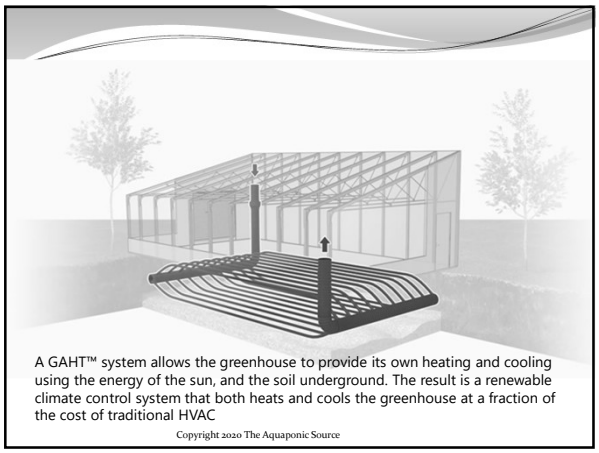

A GAHT™ system allows the greenhouse to provide its own heating and cooling using the energy of the sun, and the soil underground. The result is a renewable climate control system that both heats and cools the greenhouse at a fraction of the cost of traditional HVAC

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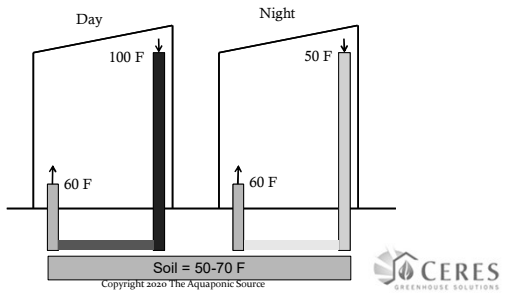
## *Ground to Air Heat Exchanger*

*Aka….Earth Tubes; Climate Battery; Ground to Air Heat Transfer (GAHT) System*

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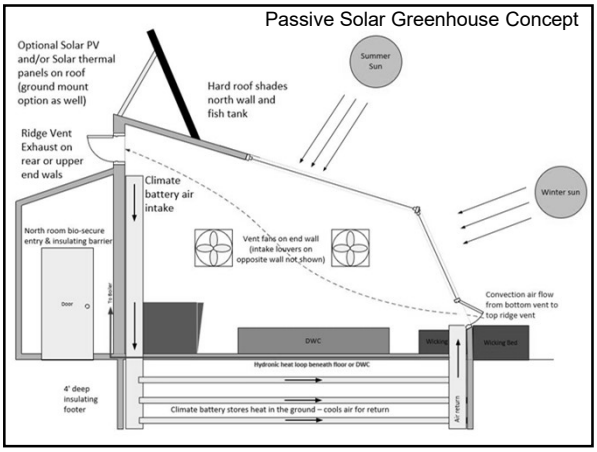
## Passive Solar Greenhouse Concept

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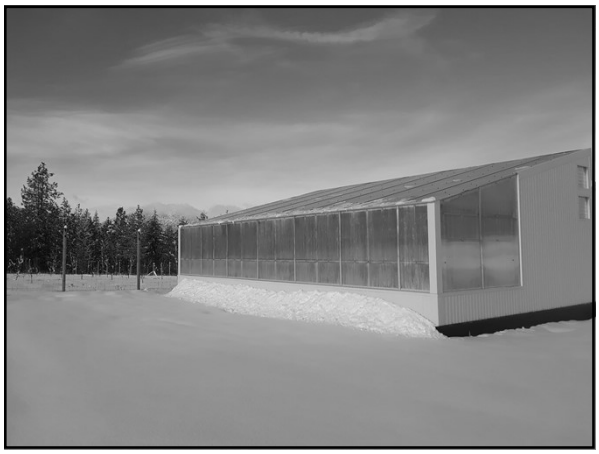

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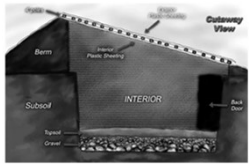
## Walipini (the underground greenhouse)

- "Walipini" comes from the Aymara Indian language and means "place of warmth"
- Locating the growing area 6'- 8' underground and capturing and storing daytime solar radiation are the most important principles in building a successful Walipini




Photos: Benson Agriculture and Food Institute
Brigham Young University, 2002

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## Walipini temperature

- When the temperature above ground is cold, say 10º F with a cold wind, the soil temperature at 4' deep in the earth will be at least fifty degrees in most places.
- Example: An underground temperature of 50º requires heating the Walipini's interior only 30º to reach an ambient temperature of 80º.
- An above ground temperature of 10º requires heating a greenhouse 70º for an ambient temperature of 80º

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## Estimated Greenhouse Costs

**$3 – $4 Metal Pipe Frame includes steel pipe, wooden-framed end walls, with plastic film cover**
**$4 - $5 Wooden Frame of construction-grade lumber, and plastic film cover**
**$6 - $7 Wooden Frame of construction-grade lumber, and single-layer, rigid plastic cover**
**$9 - $10 Wooden Frame of construction-grade lumber, and structured sheet rigid plastic cover**
**$25 - $30 Aluminum frame, concrete footings, structured sheet rigid plastic or single-layer glass cover from a kit.**
**$40 - $50 Aluminum frame, concrete footings, double-layer tempered glass cover from a kit.**

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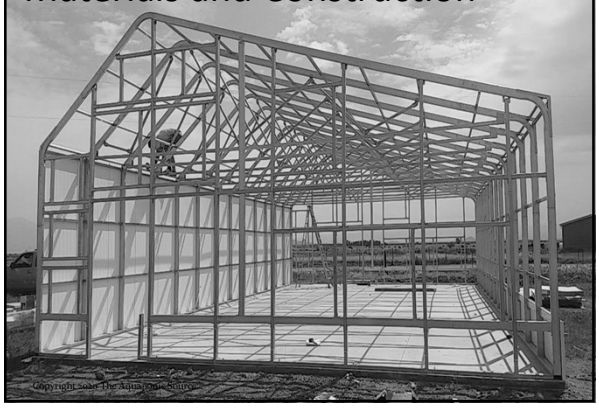
## Materials and Construction



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- Foundations and Floors
- Building Materials
- Glazing Considerations
- Insect Screening

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## Foundations

- Foundations must be level and square to properly anchor the greenhouse
- Wood is common for hobby greenhouses (under 120 sq ft) such as 4x6 or 6x6 rot-resistant treated wood or cedar
- Concrete is the most durable and may be required by your city building codes
- Foundation specifications should be coordinated with your greenhouse vendor and city planning dept.
- A slab is a common type of shallow foundation used with greenhouse structures. The slab will be about 4–6 inches in thickness and thicker at the perimeter.
- All concrete foundations should include the use of rebar to strengthen the concrete as well as steel mesh in the slab.

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## Floor Considerations

- Dirt, rock, sand – not ideal, can't be sanitized
  - Mud, pathogens, weeds, debris, plant matter
  - Concerns for stability for system weight
  - Can place paving stones down walkways
- Landscape fabric – better, can be swept, hard to sanitize
- Hardscape – concrete, brick, slate
  - Can be swept and sanitized
  - Supports weight of tanks and equipment
- Floor drains

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## Common Building Materials

- Wood is commonly used for smaller hobby greenhouses. Wood can be exposed to excessive humidity in greenhouses which can lead to warping or rot. Using redwood, cedar or treated wood are good options
- Aluminum is a rust proof metal that is commonly used and can provide a solid support structure for greenhouse
- Galvanized steel is strong and relatively inexpensive. Larger spans and fewer framing materials are needed over aluminum. Steel can wear and rust over time if exposed to excessive humidity and salinity

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## Structural considerations

- Many greenhouse companies offer standard designs based on widths such as 15', 24' or 30' and lengths in increments of 10'
- Commercial greenhouses should be engineered to local building snow and wind loads along with the capacity to support coverings, overhead equipment, lights and hanging baskets
- Look for greenhouses that can meet structural codes while minimizing structural components in order to maximize light to your crops
- Look for a good warranty plan for the structure

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## Greenhouse Loads

- Work with your local greenhouse company, extension agents or look at NGMA standards for greenhouse loads
- Dead loads – The weight of all permanent construction and building materials, rooftop, equipment
- Live loads – Temporary loading such as snow, debris, equipment – max 15lb ft2
- Wind – 70 to 90mph common design

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## Wind Load

- Wind load is typically the strongest force the building will be subjected to
- Wind forces are influenced by basic wind speed, building orientation and exposure, height, shape and doors or vents that may be open
- Wind passing over a greenhouse creates a positive pressure on the windward side and a negative pressure on the leeward side. These can combine to create a force that wants to collapse or overturn the structure
- National Greenhouse Manufacturers Association (NGMA) has developed standards to comply with IBC

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## Snow loads and management

- Typical snow load design ratings for greenhouses are 30 lbs per sq ft
- Wet heavy snow can collect in the gutters in gutter connected greenhouses. Adding a heating element underneath the gutters can help to melt and run off snow
- Running grow lights or opening an energy curtain can warm up the roof glazing to help melt snow rapidly
- Sometimes you just have to get up there and carefully brush it off to avoid accumulation

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## Covering Materials & Considerations

- Light transmission, diffusion, quality
- Heat loss and thermal resistance
- Condensation
- Durability, lifespan, replacements
- Size
- Availability
- Cost

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## Polyethylene Plastic Film

- Short life span, 3-4 years
- Covering materials are 4 to 6 mil thick
- Infrared (IR) blockers = less heat loss
- Anti-condensate AC materials
- Cost around $0.16/sq ft
- Double poly layers with air pocket in between to increase r-value and reduce light transmission
- Use outside air to inflate

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## Solexx Greenhouse Wraps

- Light weight
- Structured air pocket
- Good defused light
- Easy to install
- 10 year warranty
- 2.1 R value
- Comes in rolls or panels

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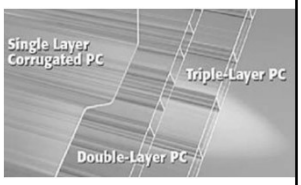
## Polycarbonate

- Easy to install
- Longer life span 10+ years
- Stronger and lighter than glass
- Flame retardant
- Widely used and readily available
- Double and triple walls provide better r-value
- Used on end walls and roof
- Cost $1.5/sq ft

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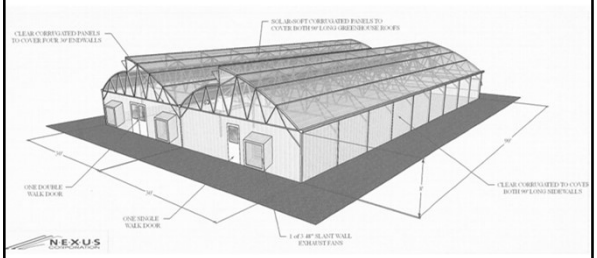


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## Glass

- Looks great, but expensive
- Provides nearly 100% light transmission of all spectrums
- Does not degrade over time from UV
- Can increase the amount of heat gain in the summer and cold in the winter
- Requires a more significant structural frame to support the weight
- Can last forever but could be subject to hail damage in certain climates

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## Insect Screening

- Depending on your climate and potential for pests, intake vents should be protected by insect screening
- Large evaporative cooling walls can be protected by an additional structure wrapped in thrip screening
- Screening also prevents larger dust and debris from getting clogged in your wet wall
- Build a hard lid sloped roof to keep snow and rain off of motors and vents

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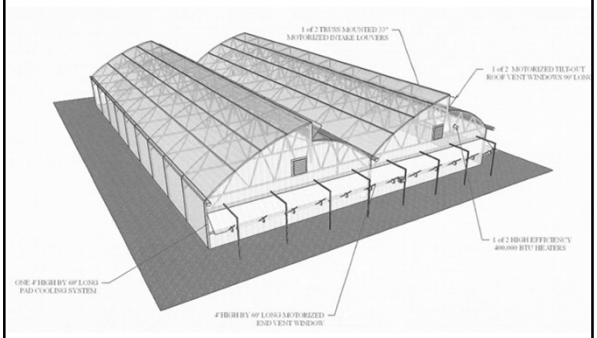


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## Interior Space Planning

- Aisles, walkways and work spaces
- Minimize excess walking
- Group space if doing classes or tours
- Physical and bio-secure entrance
- Customer front end – market, meeting space
- Shipping and Receiving
- Seed starting, germination, nursery space
- Product packing, staging and shipping
- Storage, refrigeration, food prep, etc
- Rest room, hand washing facility
- Water access, electrical outlets
- Lab area for testing, recording data, laptop
- Pesticide storage

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## Cold Storage

- Necessary to keep harvested plants food safe until delivery
- Sized according to the volume of harvest and storage
- Used to store fish feed and seeds outside of growing area
- Can be a tow-behind trailer unit, a refrigerator, a container cooler or walk in unit
- Plans for making a cooler unit are available on the internet using an insulated space, an air conditioner and a “coolbot” controller to maintain refrigeration temps

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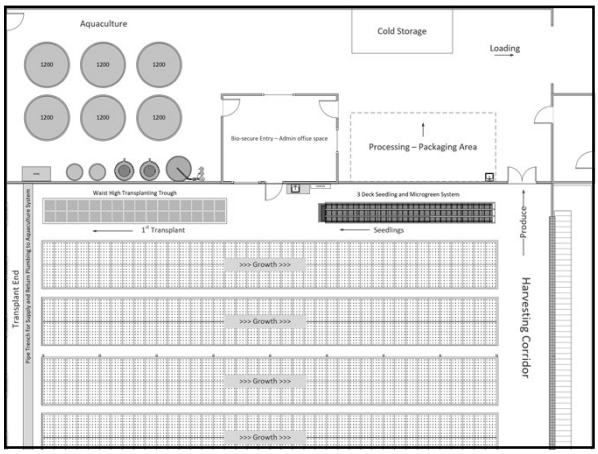


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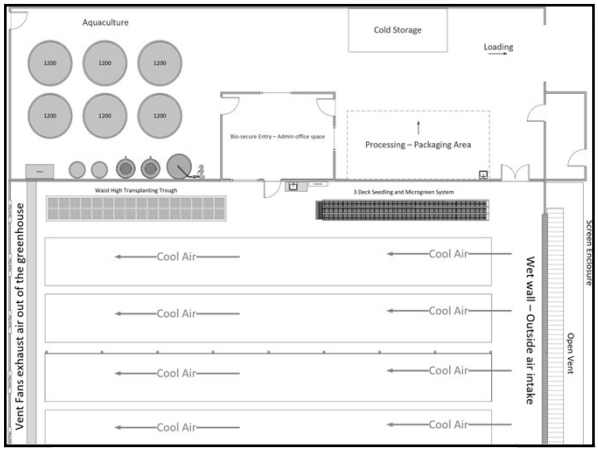


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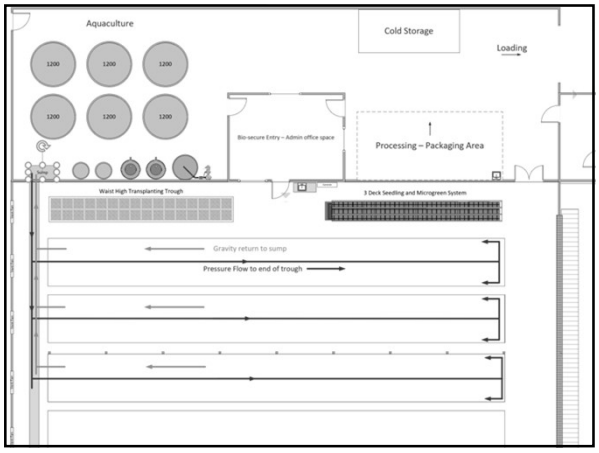


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## Exterior space planning

- Street access, gates, security
- Parking and loading dock areas, fish delivery
- Weed control outside of greenhouse
- Site slope, soils, sun and trees
- Pest, predator and other contaminant prevention
- Physical barriers and proximity to others
- Backup generator
- Site drainage from greenhouse
- Composting site, outdoor garden

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## Exterior Space Planning

- Outdoor community garden on south side of greenhouse
- Garden fence and access control
- Farmer's market house (not shown)
- Nutrient rich water and fish waste can be used and composted in the soil-based garden
- Compost piles located in garden area
- Greenhouse provides year-round production. Soil farm grows complimentary crops such as corn, potatoes and onions

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## Aquaponics Considerations

- Understand your tank footprints, circulation and plumbing requirements
- Keep fish tanks in the warmest part of the greenhouse, insulate in winter
- Don't place tanks where they will restrict airflow or cooling walls
- Filtration tanks, pump(s) and aeration
- Nursery and purge tanks
- Water storage and filtration systems
- Water discharge, floor drains
- Ensure access for fish deliveries
- Tanks and deep water culture provide additional thermal mass

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## Head House for Fish

- Consider separating fish and plants
- Greenhouse is optimum for growing plants
- Fish don't need intense greenhouse sunlight
- Utilize head house for office, processing and bio sceurity
- Maintain better temperature controls
- Repurpose barn, shed, other existing building
- May be cheaper $ psf than greenhouse

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Head house for fish system

Greenhouse for plant production

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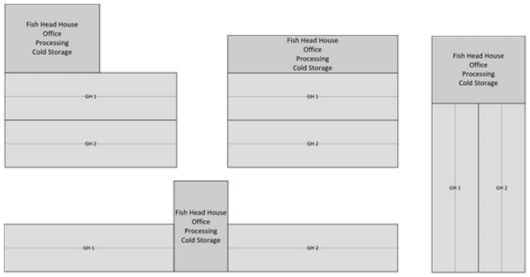
## Head House Layout Concepts

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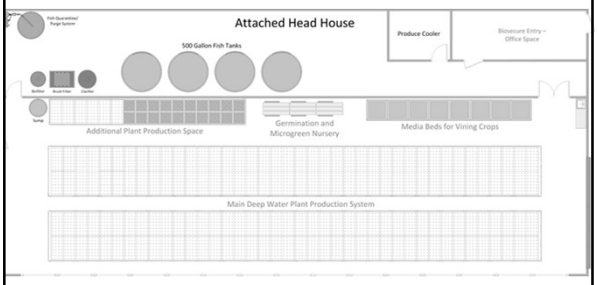
## 30 x 96 greenhouse with head house

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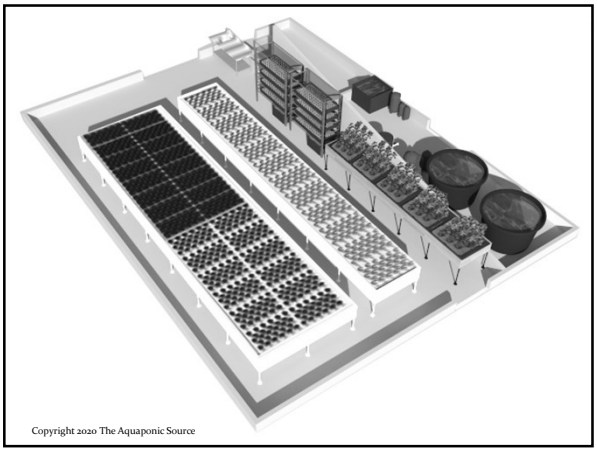

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## Repurposing

*Turkey Barn Conversion – Phase 1*

*Berthoud, CO*

*The customer removed roof panels and installed glazing, a wet wall and ventilation system.*

*Aquaponic System:*

*Growasis Elevated DWC 8' x 72'*
*8 Media beds, Transplanting trough and two deck nursery and microgreen system. Two 500 gallon tanks, Endurance 4000 filter, dual sump and dual zone Aquaheat propane water heater*

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Bella Vita FARM BROOKEVILLE, MD

*Aquaponic Solar PV Greenhouse*

*Repurposed greenhouse with solar PV array.*

*Four 500 Gallon tanks raising Koi and Tilapia*

*Four Growasis double decker systems (4' x 40' each) 1,280 total sq ft*

*1,000 heads per week, plus tomatoes and microgreens*

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## Community

*Forest County Potawatomi Farm*

*Wabeno, WI*

*30 x 100' Passive Solar Greenhouse attached to processing and education center*

*Geothermal system with phase change material on north wall*

*Two 8' x 84' Growasis DWC troughs with FIT (Filter-in-tank) raceway aquaculture system.*

*900 to 1,100 heads per week*

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BUTTERCRUNCH FARM

*Eagle, CO*

*3,000 sq ft Greenhouse with attached 1,500 sq ft fish head house with processing and cold storage space*

*Three 8' x 64' Growasis DWC troughs with double deck nursery and microgreen system*

*Four 500 gallon fish tanks producing Tilapia*

*Farm produces a wide variety of lettuce, microgreens and leafy greens for the Vail Valley region*

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Mental Health Center of Denver

*5,400 sq ft Greenhouse*

*Three 8' x 78' Growasis DWC troughs with double deck nursery and microgreen system*

*Two 2,800 gallon raceway fish tanks producing Tilapia and Catfish*

*The farm produces a wide variety of lettuce, cooking greens and microgreens for the surrounding neighborhood and local restaurants.*

*Fish are processed by Seattle Fish company 1 mile from the greenhouse*

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## Indoor Building Growing

**Barn, warehouse, shed, mall, office building, basement, garage**

- Lighting is the biggest expense
- Heating and cooling may be reduced or increased by building
- Ventilation and air circulation critical
- Biosecurity and pest management similar to greenhouse
- Zoning and building use permits may be challenging
- Vertical growing suggested to maximize footprint
- Potentially higher rent/mortgage rate and insurance costs
- Good to repurpose unused buildings
- So far not a great track record with indoor food production

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## Environmental Systems

- Greenhouse Air, Temperature and Humidity
- Ventilation and Air Exchange
- Heating considerations and methods
- Cooling considerations and methods
- Control Systems
- Energy Requirements and Backup Power

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## Greenhouse Air

*Gases and particles suspended in the building*

Air exchanges can change the mix – bringing air from outside the building inside, and pushing or pulling inside air outside

- Gases – Nitrogen, Carbon Dioxide (CO2), Oxygen (O2), other
- Water Vapor – Evapotranspiration
  - Evaporation – water going into the greenhouse air from fish tanks, sumps, Deep Water Culture, etc
  - Transpiration – water drawn through plant's roots, stem and then out thru leaves
- Particles – dust, pollen, bacteria, mold spores, fungus
- Cleaning products, pesticides, additives, plant materials, etc

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## Temperature

- Maintaining a consistent temp within the ideal range for your crops is critical for their success
- Most plants like warm days and slightly cooler nights
- For most crop production 65° - 80° F degrees is optimal
- Volatile temps in the greenhouse increase stress on crops, effects yields and product quality
- Your greenhouse and temp control systems should be designed as efficiently as possible
- Minimizing energy inputs as much as possible will help increase profits and reduce pollution and waste

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## Humidity and Relative Humidity (RH %)

*It is a measure of how much water is in the air versus how much water the air can hold at the same temperature*

- Measured in a percentage, 100% saturation is called the "dew point" – this can cause your greenhouse to RAIN
- Most crops do well with relative humidity of 45 – 75%
- Seedlings can take higher humidity than older crops because they are smaller allowing more air flow
- Humid climates may need to be dehumidified
- Hot air holds more humidity, cold air less humidity
- Some greenhouse films have an anti-condensation coating

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## Vapor Pressure Deficit (VPD)

- The *difference in pressure* between the air's water content and the saturation point – this effects transpiration.
- VPD calculated with Relative Humidity and Temperature

- High VPD (means low RH) – plants lose water more rapidly and dehydrate which can slow growth rates or cause desiccation
- Low VPD (means high RH) – plants cannot transpire water or draw nutrients which can cause deformity, tip burn, rot, disease, fungus, powdery mildew and pest pressure

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## Carbon Dioxide (ppm)

- Needed for plant photosynthesis
- Outside air at 415 ppm as of summer 2020
- Plants respond well to CO2 in 800 to 1,200ppm range
- Some growers supplement CO2 in controlled environment
- Low C02 reduces yields and growth
- Fish tanks off gas CO2 into the atmosphere naturally contributing to the CO2 levels
- Plants take in CO2 and produce Oxygen (O2) used by the fish

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## Microclimates

Places in the greenhouse that experience special conditions

- A build up of heat directly under the heater(s)
- Intense heat and scorching sunlight by the south glazing
- Cooler and darker areas in the back, north corners
- Cool or hot areas (depending on season) by vent walls
- Cool, wet areas near the wet walls
- Shaded and drippy areas under the gutter connects
- Areas shaded by larger vining plants
- Areas under artificial lights which can affect temperature
- Incorrect placement or timing of vents, fans, shading, etc.

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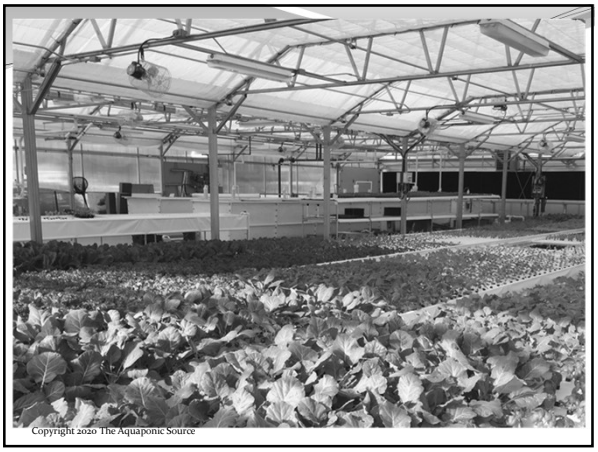


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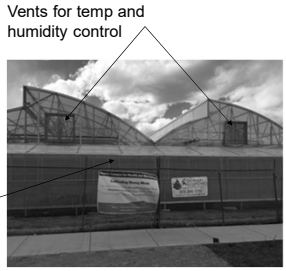
## Ventilation and air exchange

Exchange of air between inside and outside of greenhouse

- Temperature control
- Humidity control
- Gas exchange
- Airflow to plants
- Important in both summer and winter

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## Ventilation Basics

Natural or Passive ventilation happens through

- Open roof or ridge vents
- Warm air rising through convection allowing hot air to escape
- Side inlet vents or roll-up side systems
- Open doors or windows can create passive airflow

*Passive ventilation may be inadequate for plant production*

Mechanical ventilation happens through

- Vents or louvers being opened by temp or humidity trigger
- Exhaust fans pushing or pulling air through the building
- Air exchange continues until temp or humidity gets within range

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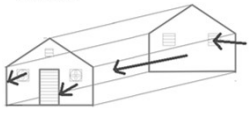
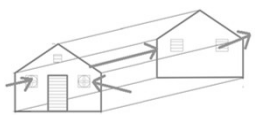
## Mechanical Ventilation

- **Exhaust fans should be sized to exchange the total volume of greenhouse air in one minute.**

**Negative pressure system**
- Vent opens on cool side of building
- Exhaust fans draw air out
- DO NOT turn fans on for long periods of time without vent being open, it could cause glazing to **contract**



**Positive pressure system**
- Fans on cool side of building blow air in
- Air exits through exhaust outlets or passive louver vents
- DO NOT turn fans on for long periods of time if vents are blocked since this can cause glazing to **expand**



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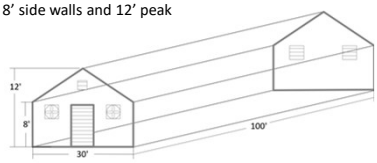
## Ventilation calculations

- Basic Formula is CFM = Velocity x Area. Example Greenhouse: 30 x 100' with 8' side walls and 12' peak




1) Determine the area of the end wall (30x8) + (30x4)/2 = 300 sq ft
2) Velocity = length the air must travel in one minute = 100 ft
3) CFM = 300 x 100 = 30,000. Therefore the combination of fans and corresponding inlets must allow for air flow of 30,000CFM
4) Work with your greenhouse equipment supplier to properly size your exhaust fans and louvers. Variable speed fans allow for different exhaust rates depending on the season and temps

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## Vent Opening Options

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## Exhaust Fans

- Dual - stage (low, high), often 3 Phase 240v
- Dimensions and number of fans related to CFM requirements

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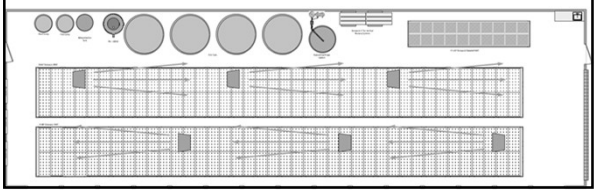
## Air Circulation

- Horizontal air flow (HAF) fans move air around for circulation and temperature uniformity
- Place fans to develop a circular rotation pattern
- HAF fans can help to push the heat from forced air heaters around the greenhouse



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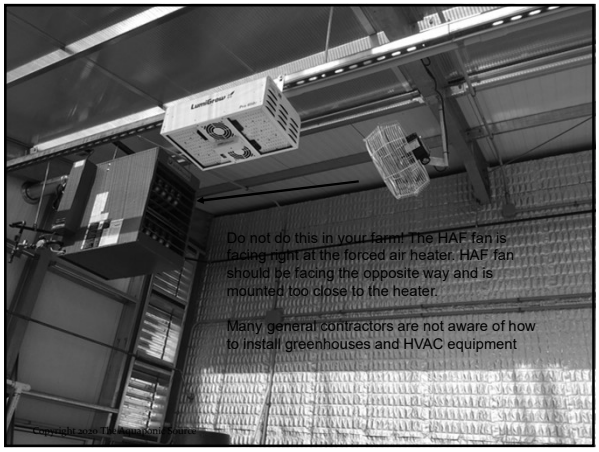


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## Dehumidification

- If the outside air and inside air are BOTH saturated, then ventilation and circulation won't be completely effective
- One option is to reduce indoor air temperature, to be closer to outside temp (cold air holds less water)
- Dehumidification draw water out of the air and condenses (collects it) as water
- Commercial dehumidifier – refrigerant types cool greenhouse air then recapture the water, big energy users
- Cold dehumidify is a process in the winter, upper vent opens to draw air in, heater turns on and, exhaust fans draw humid air out.

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## Heating Considerations

- Fuel source, costs
- Heating water vs. air
- Hot air rises, cold air drops
- Maximize thermal mass to store heat
- Understand your temperature differential
- Plant species, seasonality
- Venting the heating system

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## Heating Methods

- Insulation and heat curtains (heat containment)
- Geothermal (climate battery)
- Thermal mass (aquaponic system)
- Radiant floor heating
- Radiant spot heaters
- Forced air heaters
- Phase change material
- Wood or pellet stoves

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## Determining the amount of heat

- Heat Energy is measured in BTUs (British Thermal Units)
- Heat formula is Q=A x U x (Ti – To)
- Q = BTUs of the heating system
- A = The total surface area of all sides, end walls and roof
- U = Heat loss factor for your covering material
- Ti = The desired inside temperature
- To = The lowest outside temperature
- A handy online calculator can be found here: https://www.gothicarchgreenhouses.com/Greenhouse-Heater-Calculator.htm

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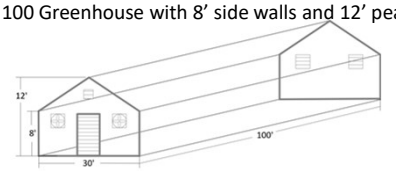
## Heat calculation example

- 30 x 100 Greenhouse with 8’ side walls and 12’ peak




- Total surface area of 30 x 100' greenhouse shown (A) ≈ 5,200 sq ft
- Minimum Outside Air temp (To) = 0
- Minimum desired inside air temperature (Ti) = 65
- Heat loss factor for double wall acrylic covering (U) = .54
- 5,200 x .54 x (65 – 0) = 182,520 BTUs

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## Insulation

- Insulate the north wall and north roof if possible
- Seal up around vents, holes, cracks, doors, etc
- Add another layer of clear poly with air pocket
- Avoid heat loss in tanks, rafts, sump, etc.
- Insulate system components to maintain temp
- Retractable insulation blankets, heat curtain
- Thermal mass/geothermal inside and out
- Insulate the foundation (if there is one)

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## Radiant floor heating

- Uniform temperature at ground or plant level
- Warm air rises through greenhouse
- Hot water loops more efficient
- Natural gas, propane, Solar hot water
- Nice under DWC

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## Heat loop under your troughs

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## Radiant spot heaters

- Heats a specific area
- Does not heat the air, only heats objects directly under them
- Ideal for locations above doors that frequently open to cold outside air or for certain indoor plants that need heat (tomatoes in the winter for example)

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## Forced Air Heaters

- Very common in greenhouses
- Natural gas, propane or hot water
- Inflated distribution tubes “heat sock” can increase distribution through the greenhouse and efficiency
- Heat cold outside air during air exchange
- Used with a thermostat or controller

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## Phase Change Material

- Evens out temperature swings – latent heat fusion
- Reduces energy costs (both heating and cooling)
- Saves space: Built into the wall
- Is easily installed in any greenhouse – comes in 4 x 8 sheets


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## Wood or Pellet Stove

- Can be used to heat air or water
- Needs to be fed to maintain temperature
- Can have an autofeeder
- Known issues with smoke if installed indoors and there is a problem
- "Rocket mass heaters" can be used very intermittently, but can also be dangerous

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## Fuel Type and Cost

- Propane – good option for remote locations, truck delivery
- Natural Gas – delivered by power company, hard lined
- Wood and pellets – for combustion type systems
- Geothermal – well, GAHT, climate battery, air or water
- Solar Thermal – Using the sun to heat air or water (doesn't work when there is no sun)
- Electric – May be only option, may be very expensive
- Fuel Oil – Common in older greenhouses, especially in the Northeast and Midwest, not so common for new installs

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## Cooling a Greenhouse

- Geothermal (climate battery)
- Roll up sides, vented ends, roof vents
- Greenhouse fans
- Wet walls, swamp or evaporative coolers
- Shade cloth, retractable systems
- Fogging and misting systems

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## Cooling Considerations

- Air Temperature
- Moisture and condensation
- Cooling can be more expensive than heating (electricity consumption)
- Crop selection, challenges with bolting
- Water at root zone helps in high temperatures
- Wet walls are less effective or not at all in humid areas
- More crop damage from heat than cold

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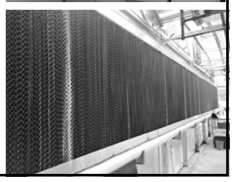
## Evaporative cooling

- Fans draw air across wet wall to lower air temperature which in turn increases humidity
- Evaporative cooling walls work best in dry climates
- Overhead foggers and misters can also be used to distribute moisture and cooling
- DO NOT use aquaponic water for wet wall or foggers
- Use sanitizer in reservoir to clean wet wall and keep safe



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## Small Evaporative coolers

- For small greenhouses, swamp coolers can be wall mounted or floor standing

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## Shading a Greenhouse

- Shade cloth inside – heat gain at roof peak
- Shade cloth outside – deflects light/heat
- Reflective material Aluminet
- Shade cloth – graded by light transfer percentage usually between 30 to 90 percent light transmission

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## Retractable shade cloth system

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## Basic control equipment

- Thermostats - Control fans or heaters based upon temperature settings. Differential settings determine how many degrees the temp has to change before your equipment turns on or off. This prevents equipment from turning on and off constantly
- Timers – Control equipment based upon a minimum length of continuous operating time (minutes, hours or days) Electronic or mechanical timers are available.
- Lighting Timers – Used for high load lighting systems with multiple light fixtures
- Speed controllers – Used for adjusting the speed of a variable speed fan motor

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## Greenhouse controllers

- Reduces labor and energy costs
- Manages heating and cooling set points in stages
- Venting system controls – temp, humidity, rain
- Shading, night curtain controls – light sensors
- Power outage monitors, backup generator
- Security and alarm systems
- Lighting systems – timers, light sensors
- Response systems – call, text, email, video, webcams
- Improves crop quality

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## Controller Accessories

- Items designed to work with your environmental controller to better optimize your environment
- Temperature sensors
- Humidity sensors
- Light sensors
- Weather stations
- PC or phone based software

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## Electrical equipment tips

- Greenhouse environments are prone to humidity and condensation particularly in the winter months when warm inside air meets outside cold air
- Timers, thermostats, controllers and electrical outlets should be enclosed in NEMA 4 rated waterproof enclosures.
- It's important to know the voltage, amperage or horsepower of the equipment being controlled.
- As always, working with your equipment supplier is the best way to ensure you are selecting control equipment that will best fit your needs

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## Renewable Energy Opportunities

- Focus on passive solar principles where possible
- Solar powered vent openers
- Solar PV to power the greenhouse
- Solar thermal water
- Accessing wind powered energy suppliers
- Geo thermal systems
- Compost heat
- Anaerobic digestion

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