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• history

• roof structures

• greenhouse complexes

• structures inside of a greenhouse

• statics concerns and norms

http://steampunktendencies.tumblr.com/post/154058868184/the-villa-marias-greenhouse-before-1985-and
WHY DO WE BUILD GREENHOUSES

Create the best growing environment for a plant

- Shield from unwanted outside climate and organisms
- provide additional resources if needed and feasible

https://www.greenhousecatalog.com/greenhouse-covering
GREENHOUSE STRUCTURES HISTORY: ORANGERY

- earliest Orangery around 1550
- hibernation
- solid structures made of bricks with huge windows
- made almost exclusively for royals
- exotic citrus fruits
• exotic fruits and ornamental plants
• brought back from the new world
• needed protection in new glasshouses
• often in royal botanical gardens

https://www.ianvisits.co.uk/blog/2011/07/15/kew-gardens-the-glasshouses/
AROUND 1900 FIRST COMMERCIAL GREENHOUSES

- technological advancement
- cheaper heat

- longer growing seasons possible
GREENHOUSE STRUCTURES

- orangery
- botanical garden
- commercial use
- now
GENERAL ROOF-TYPES

isosceles

Saddleback roof

Shed-roof

Tunnel greenhouse

Arch greenhouse

Gothic arch greenhouse

Max et al. 2012
GREENHOUSE STRUCTURES
depend on:
• climate
• budget
• purposes:
  • crop
  • research
  • aesthetics
• (European) norms
  • static load
  • snow load
  • wind load
• fire safety

https://www.americanagriculturist.com/custom-farming/deep-winter-greenhouses-everything-you-need-know

CGI rendition of a Seawater Greenhouse © Charlie Paton
AVERAGE SOLAR RADIATION TRANSMITTANCE

Transmission of direct light, %

Position: Hannover, D (lat. 52° north)
Single span EW

Dec Mar Jun

Time of day, h

Von Elsner et al., 2000
SADDLE BACK ROOF

• roof angle and size good for light transmission

• good climatization because of high ceiling
• high light transparency to the south, good isolation to the north

• used in solar greenhouses with low energy footprint

• north wall used as energy buffer

https://ezgro.garden/ezgro-commercial-greenhouse/
TUNNEL

- low cost
- plastic film
- Lightweight
- not space efficient

• like tunnel but with sidewalls
• better ventilation
• more space
• higher structural needs
UNEVEN ARCH

• vents in the roof truss

• used when excess heat is a major problem

• often combined with insect nets as walls

• used in the tropics to shield against rain and insects


Max et al. 2012
GOTHIC ARCH

• higher rooftop than arch

• less structural

• reinforcements in the roof area needed

• higher usable volume
SPECIALIZED GREENHOUSES

Davies Alpine House
• build to keep inside cold

Eden Project
• big air filled plastic film hexagons form a dome
GREENHOUSE COMPLEXES
GREENHOUSE COMPLEXES

• single span = one roof one building unit

• multi span = multiple roofs on multiple building units

• Venlo = multiple roofs on one building unit
SINGLE SPAN

- easy to build in most cases
- not energy nor space efficient if more than one is build next to each other (like below)
- better to vent (sidewall ventilation)
- sidewall height limited by roof height
• higher ground areas lead to higher Roof areas
• the roof angle shouldn’t be changed (26.5°) as sunlight gets deflected more at shallow slopes

Max et al. 2012
• multiple greenhouses connected at roof gutter
• each roof supported by own sidewall-like structures (with or without cover material)
• more energy efficient since less hull area is exposed
• at some width difficult to deal with forces of heavy roofs
  • reinforcements in the roof and especially sidewalls required

http://www.bridgegreenhouses.co.uk/widespan-glasshouses/
• Not each roof supported by sidewall structures
• each roof has the same width, independent of greenhouse-ground-area
• Static load of roofs only small in scale and effected area
  • Highly flexible building sizes (width & length)
  • taller sidewalls unproblematic
WIDE SPAN AND VENLO
INNER WORKINGS OF A GREENHOUSE
SCREENS

http://www.bridgegreenhouses.co.uk/horizontal-screens/


VENTILATION

free

sidewall

https://articles.extension.org/pages/32535/greenhouse-ventilation

forced

roof

http://www.thegreenhousecompany.net/options/attachment/palmetto-roof-vents/

https://gothicarchgreenhouses.com/instructorpackages.html

https://www.vetteoe.com/v-flo.html
VENTILATION WITH FLEXIBLE COVER MATERIAL

https://www.wintergardenz.co.nz/ventilation.html

https://www.rimolgreenhouses.com/greenhouse-series/noreaster
VENTILATION SOLID COVER MATERIAL

https://www.farmtek.com/farm/supplies/prod1,ft_shutters_events:pg111676.html

http://www.idrotermserre.com/greenhouses/cabrio-en-GB/

http://prinsusa.com/products/structure/
VENTILATION MECHANISM

Von Lisner et al., ZUUU


HEATING

http://www.fritegotto.it/Formazione-Summer-School-Greenhouse-Horticulture/

http://www.greenhousegrower.com/technology/5-new-heating-options-for-the-greenhouse/

http://blog.maripositas.org/horticulture/greenhouse-heating-systems

http://www.northernpolytunnels.co.uk/commercial-range/greenhouse-heaters.html
DIRECT AIR HEATING

- easy to install, easy to remove
- relatively low efficiency
- temperature gradients likely
- CO$_2$-enrichment possible (gas burner)

http://www.vernon.gr/default.aspx?Index=999&Id=120&LangId=2
RADIATION HEATING

• fixed and costly to rebuild (boiler)

• if used in crop/under table quite energy efficient

• energy distribution centered around pipes not around heater
FERTIGATION

- Depending on (number of) crops used
- Size of Greenhouse
AQUAPONICS

- Fish farming and plant growing together
- Difficult to automatize
  - Two connected systems
  - Different needs
  - Influencing each other
  - Lots of variables to monitor

VERTICAL GARDENING
ALGAE FARMS

• Still new
• not commercially viable on broad scale
• Mostly lettuce and small leafy plants

• even fewer examples than V.G.
• used for biotechnological products produced by genetically modified algae
STATICS CONCERNS AND NORMS

(a) Peach-type greenhouse

(b) mono-span-type greenhouse

Wind pressure coefficients (dimensionless)

Kyeong-seok Kwon et al. 2016
CONSEQUENCE CLASS:

• how dangerous is a failure for humans or economy (needed for statistical statics calculations)
  • Rank 1 to 3
• greenhouses are CC1: low risk ➔ low reliability needed for statically concerns
  • rare presence of authorized personal, no public, no traffic area
• Same for Earthquake safety: low risk = low importance factor
planned life span of greenhouses (structural integrity):
• solid cover: 15 years
• flexible cover: 5 years
• greenhouses used as commercial area (store): planned for up to 50 years (=low structural failure rate)
• reevaluation needed after planned lifespan is exceeded
• Important for risk assessment
SNOW LOAD

• generally not a problem if hull material single layer and greenhouse is heated.
  • snow glides on water films even on small slopes
  • but: Need to prevent Freezing of gutters

http://www.uni-kassel.de(fb14/geohydraulik/Lehre/Hydrologie-II/Hydroroll_Sum17.html

Pertermann et al. 2011
SNOW LOAD

snow load calculation depending on:

- Heigth above sea level
- “Surrounding” correction value
  - Can Snow be removed by wind or added by trees
- Temperature correction value
  - Melting: k-value * inside T
- Lifespan correction factor
  - How likely will it encounter a Maximum Load of X within it’s life span
And also:
- Roof angle
  - Sliding
- Heated gutters
  - Needed for gliding
- There is a Minimum:
  - 0,25 kN/m² or 0,5 kN/m² for commercial
- Minimum temperature inside depending on Cover-Material
  - If your calculation is based on a temperature, this temperature needs to be held while snowing
In Greenhouses with solid hull material less of a problem since thermal expansion dampeners can dampen wind pressure as well
WIND LOAD

• Height of terrain
• Roughness of terrain
  • buildings, vegetation
• Topography
  • cliffs, hills
• Turbulence intensity
  • gusts
WIND LOAD

- Lifespan
  - Gumbel
- Structure specific variables
  - Tables, lot’s of Tables
- Pressure / suction on openings
  - Vents

Pertermann et al. 2011

http://www.uni-kassel.de/fb14/geohydraulik/Lehre/Hydrologie_II/HydroII_Sum17.html
OTHER LOADS TO CONSIDER

• Installations inside: Minimum 0.07 kN/m² (solid cover)
  • Planed installations need to be considered separately
• „Human load“ for e.g. repairing 1kN on most unfavorable point to 0.5kN else
  • Cleaning Robots etc. need to be considered separately
• Plant load: form 0.15 kN/m² to 1 kN/m² (heavy Pots)
  • If ropes are used (Tomato/Cucumber) this needs to be added depending on spacing and length of the rope

http://jancogreenhouse.com/customer-service.html
FIRE SAFETY

• Biggest threat: Energy screens
  • Needs to be B s1 (low flammability + no smoke generation)
• Plastic Films can even be F (highly flammable), since they normally just melt in seconds
• Glas and Aluminum do not burn (A1).
• Fire detectors normally not needed: Climate Computer does the job.
• Smoke can be let out by vents

http://marijuanaretailreport.com/fire-at-award-winning-loudpack-farms-was-caused-by-cigarette/
ALSO: CLIMATE CHAMBERS


• metal strut needs to be build according to tensile strength of glass
• overhead minimum bending tensile strength for 4mm float glass: 14,5 N/mm²