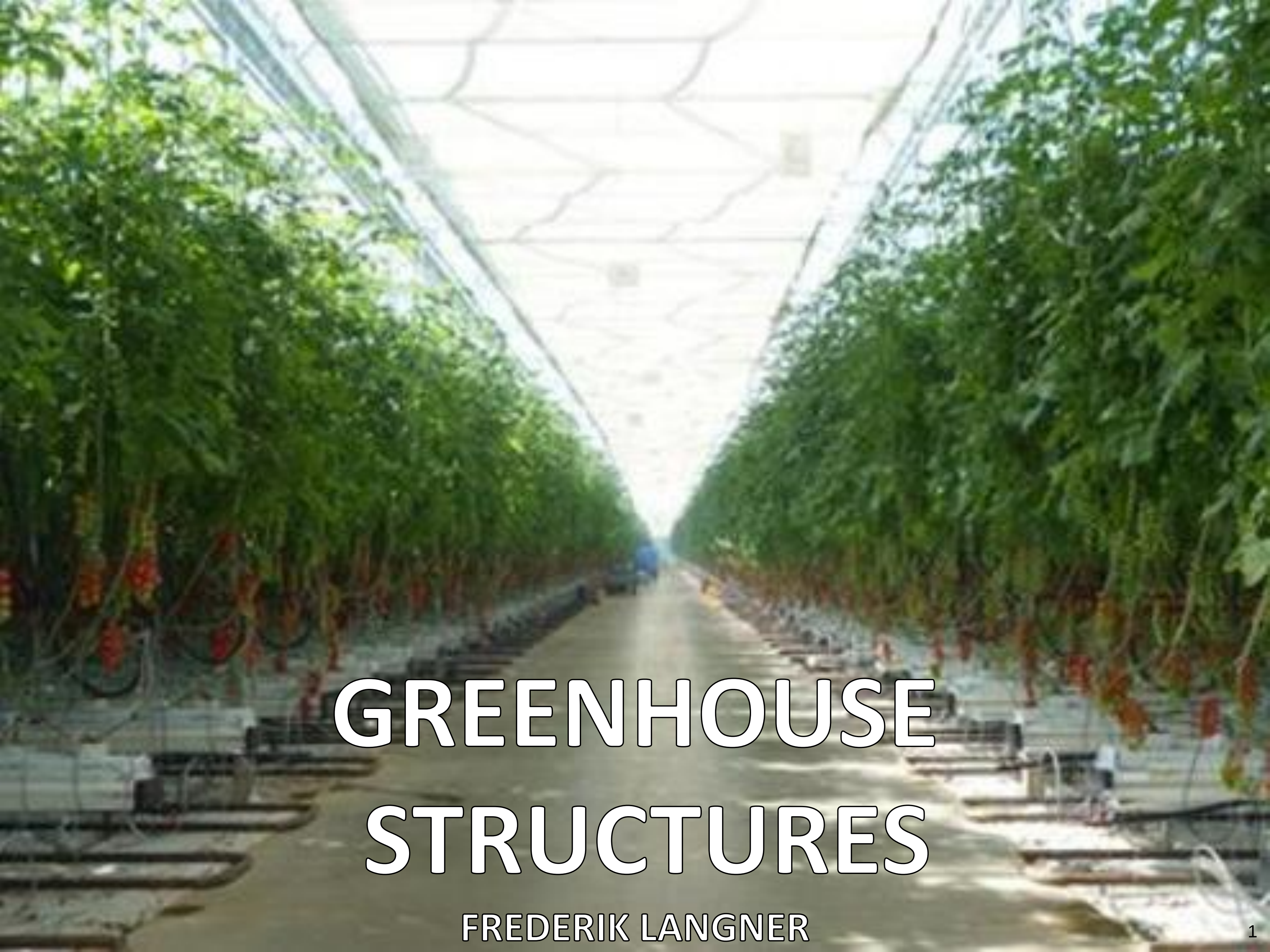
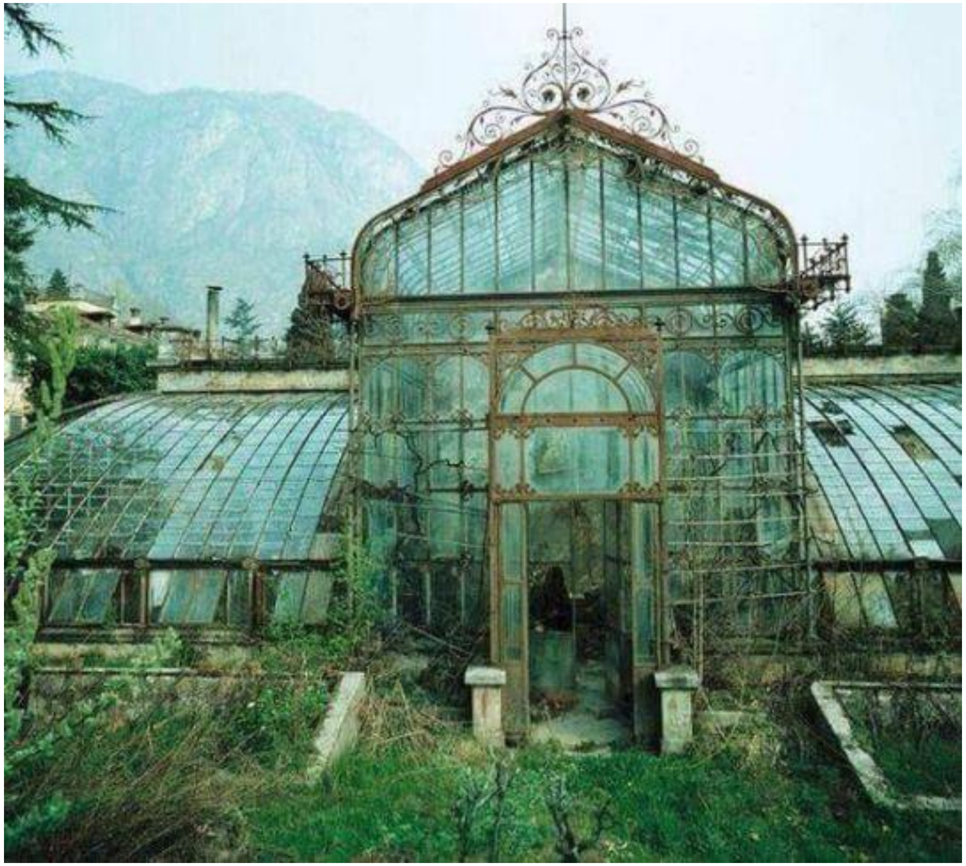


GREENHOUSE STRUCTURES

FREDERIK LANGNER

CONTENTS

- 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

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

www.chateauversailles.fr.


Inventory of the Historical Monuments in London, Volume 2, West London (London, 1925), p. 114.

GREENHOUSES IN BOTANICAL GARDENS

- exotic fruits and ornamental plants
- brought back from the new world
- needed protection in new glasshouses
- often in royal botanical gardens

AROUND 1900 FIRST COMMERCIAL GREENHOUSES

- technological advancement
- cheaper heat

- longer growing seasons possible

GREENHOUSE STRUCTURES

orangery

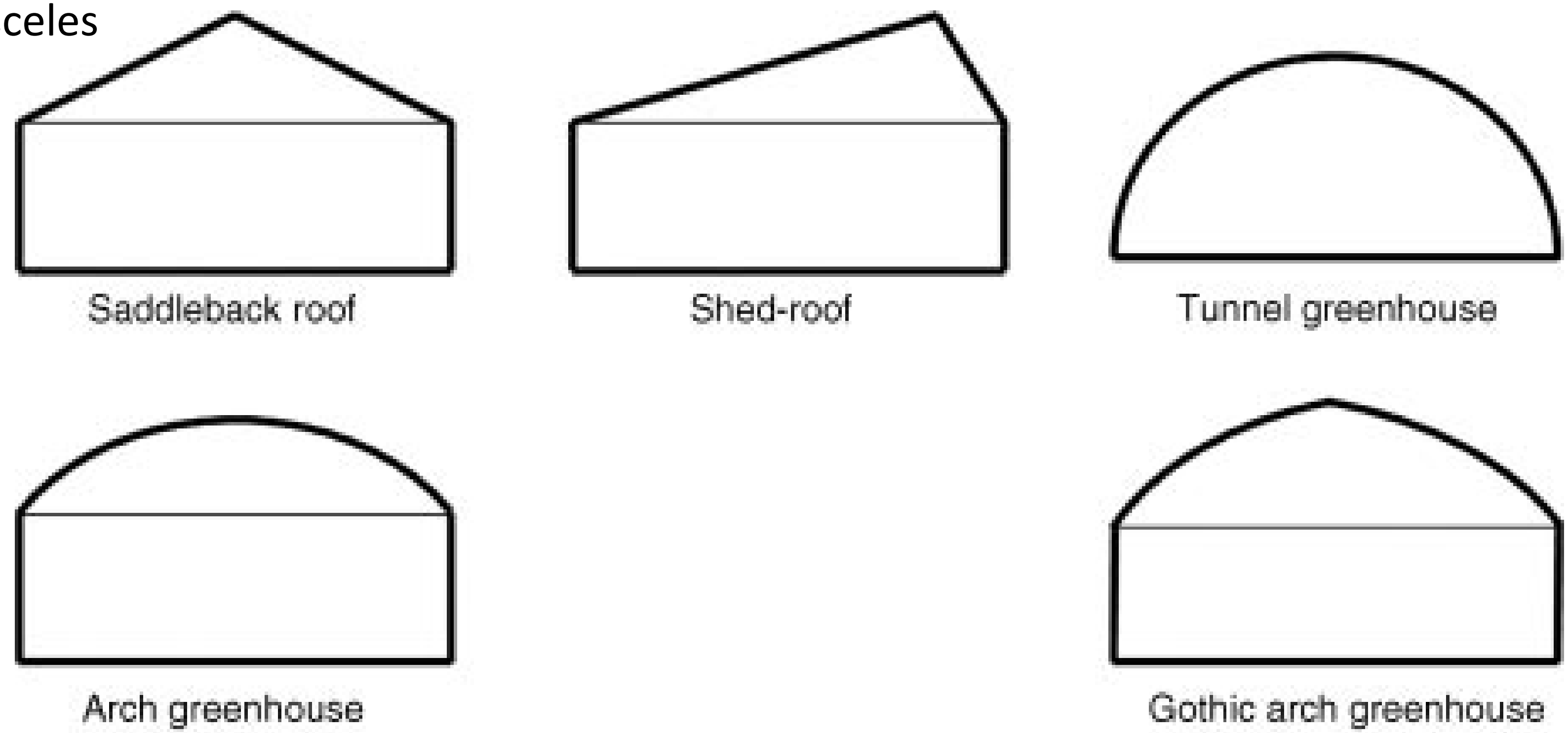
botanical garden

commercial use

now

GENERAL ROOF-TYPES

isosceles



Max et al. 2012

GREENHOUSE STRUCTURES

Hochschule Geisenheim University

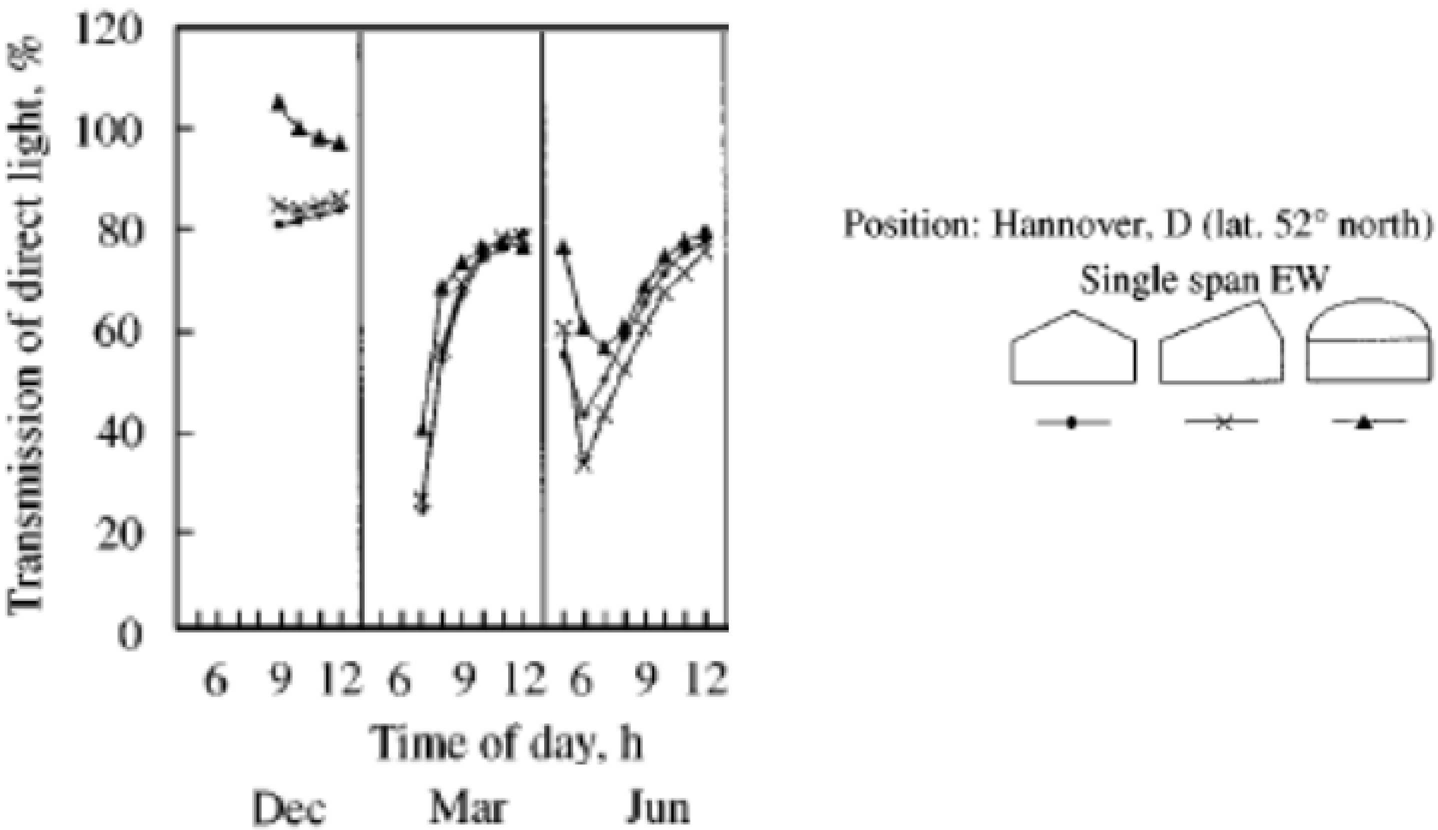
depend on:

- climate
- budget
- purposes:
    - crop
    - research
    - aesthetics
- (European) norms
    - static load
    - snow load
    - wind load
    - fire safety

CGI rendition of a Seawater Greenhouse © Charlie Paton

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

AVERAGE SOLAR RADIATION TRANSMITTANCE



Von Elsner et al., 2000

SADDLE BACK ROOF

- roof angle and size good for light transmission

- good climatization because of high ceiling

Foto: www.lillikehl.ch
Architektur: www.wilhelm-hovenbitzer-partner.com

SHED-ROOF

- 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

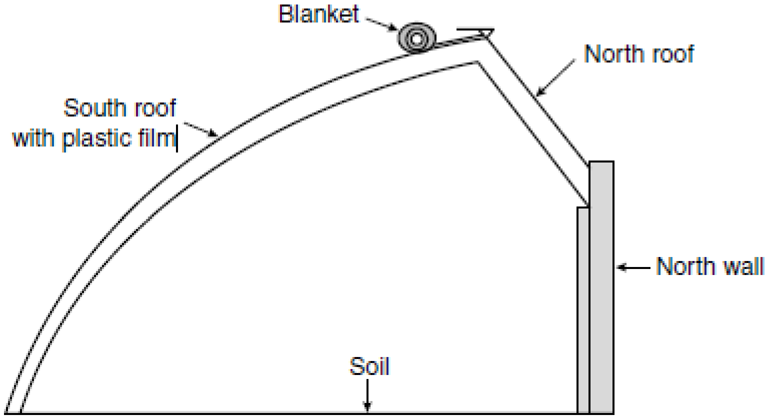


Fig. 7.9. The Chinese solar greenhouse. (Drawing: H.-J. Tantau).

Max et al. 2012

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

TUNNEL

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

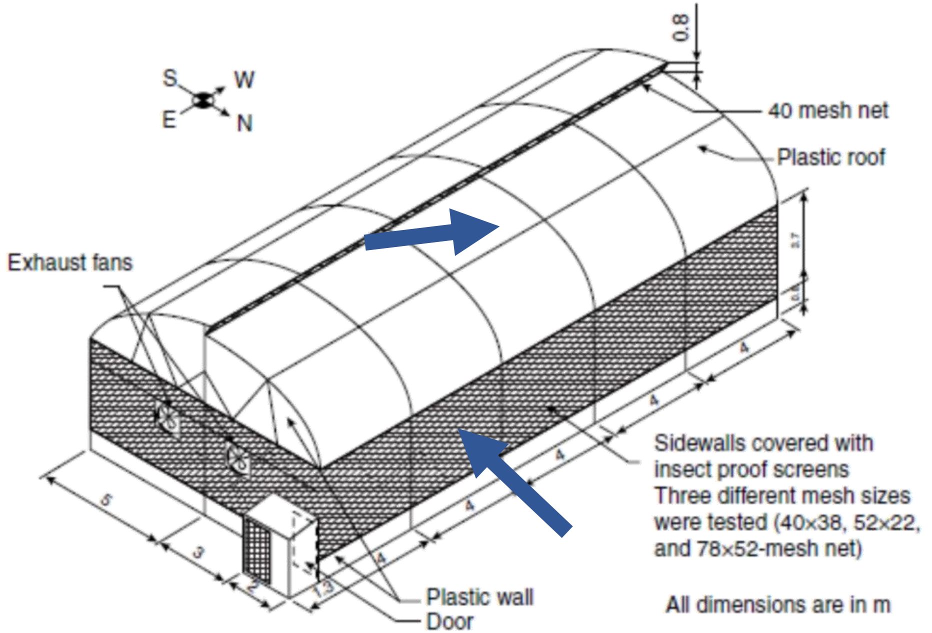
https://growerssupply.wordpress.com/2014/09/11/planning-the-planting-layout-of-a-high-tunnel/

ARCH

- 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

https://www.ulmaagricola.com/en/news/greenhouses-for-tropical-climate/

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

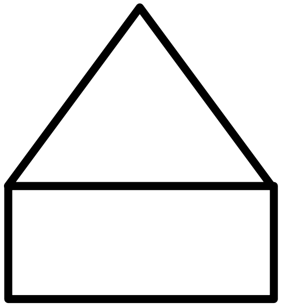
- big air filled plastic film hexagons form a dome

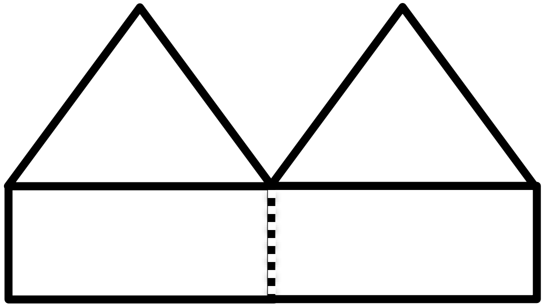
GREENHOUSE COMPLEXES

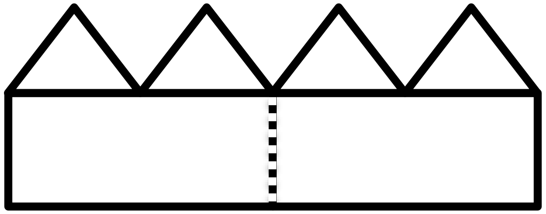
https://www.amusingplanet.com/2013/08/the-greenhouses-of-

GREENHOUSE COMPLEXES

- single span = one roof one building unit
- multi span = multiple roofs on multiple building units
- Venlo = multiple roofs on one building unit







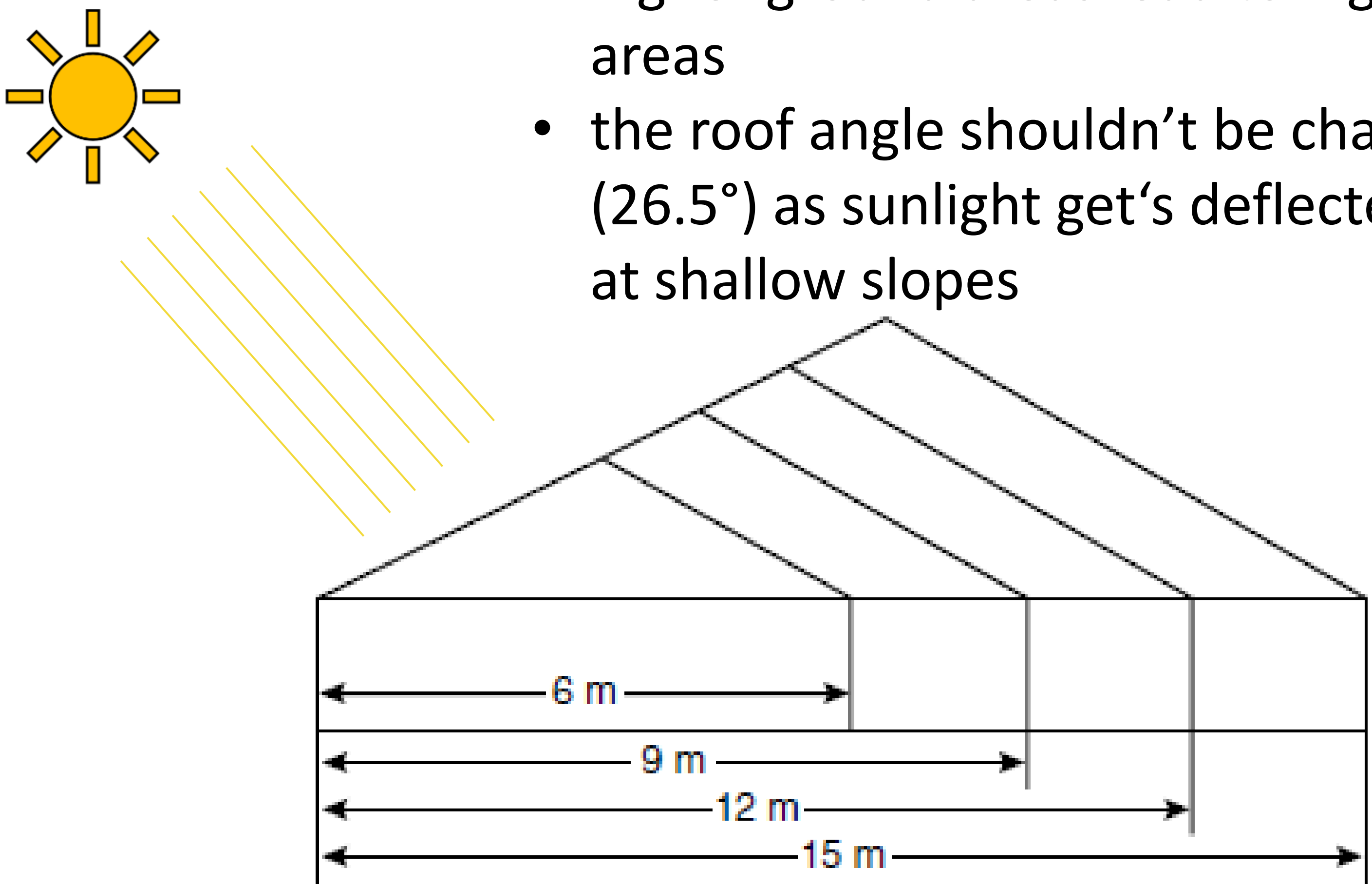
SINGLE SPAN

- 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


https://plantagreenhouses.com/commercial-farming/

SINGLE SPAN WIDTH

- higher ground areas lead to higher Roof areas
- the roof angle shouldn’t be changed (26.5°) as sunlight get‘s deflected more at shallow slopes



Max et al. 2012

MULTI SPAN

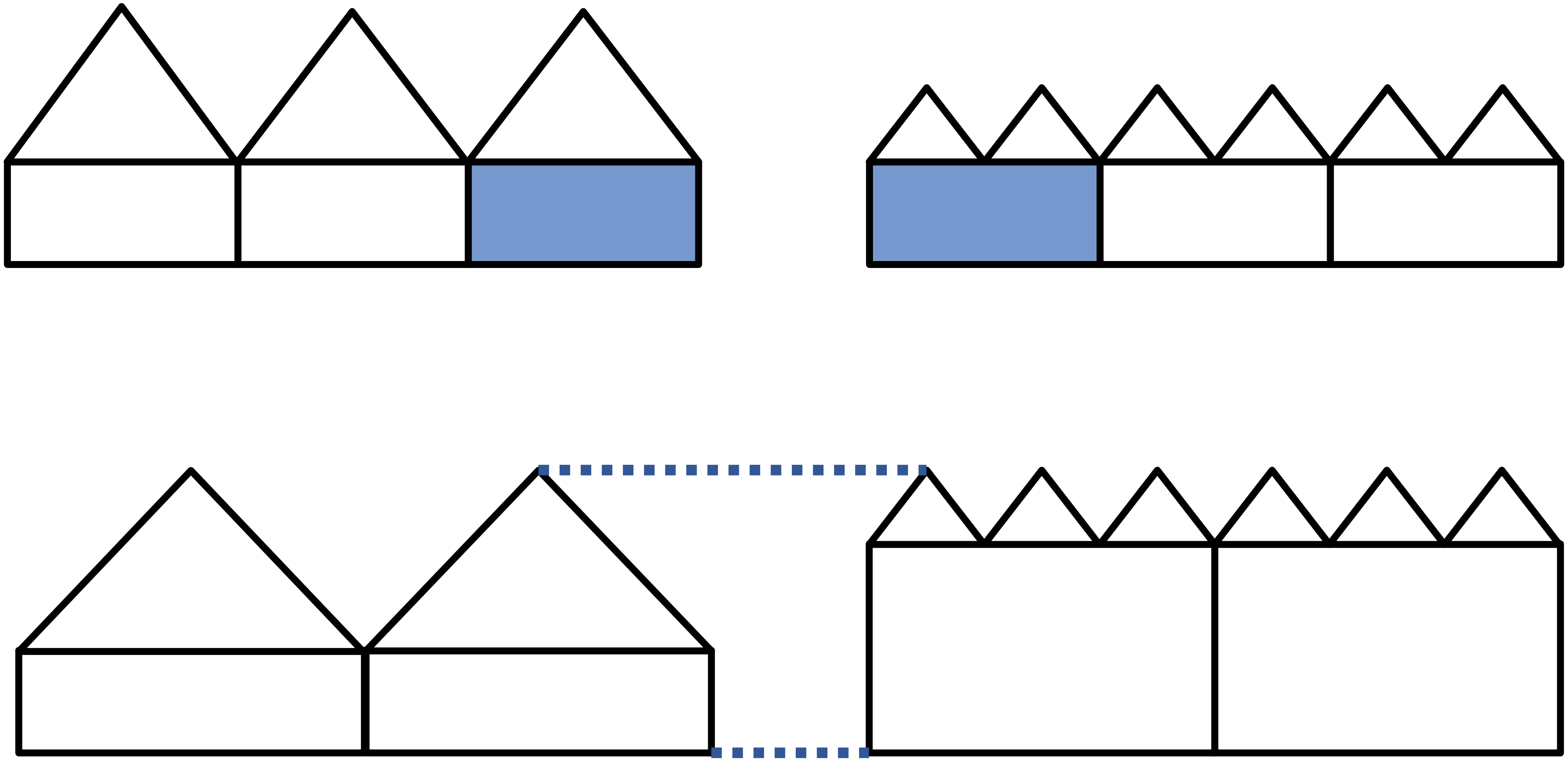
- multiple greenhouses connected at roof gutter
- each roof supported by own sidewall-like structures (with or without cover material)
- more energy efficient since less hull area is exposed
- at some width difficult to deal with forces of heavy roofs
  - reinforcements in the roof and especially sidewalls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

VENLO

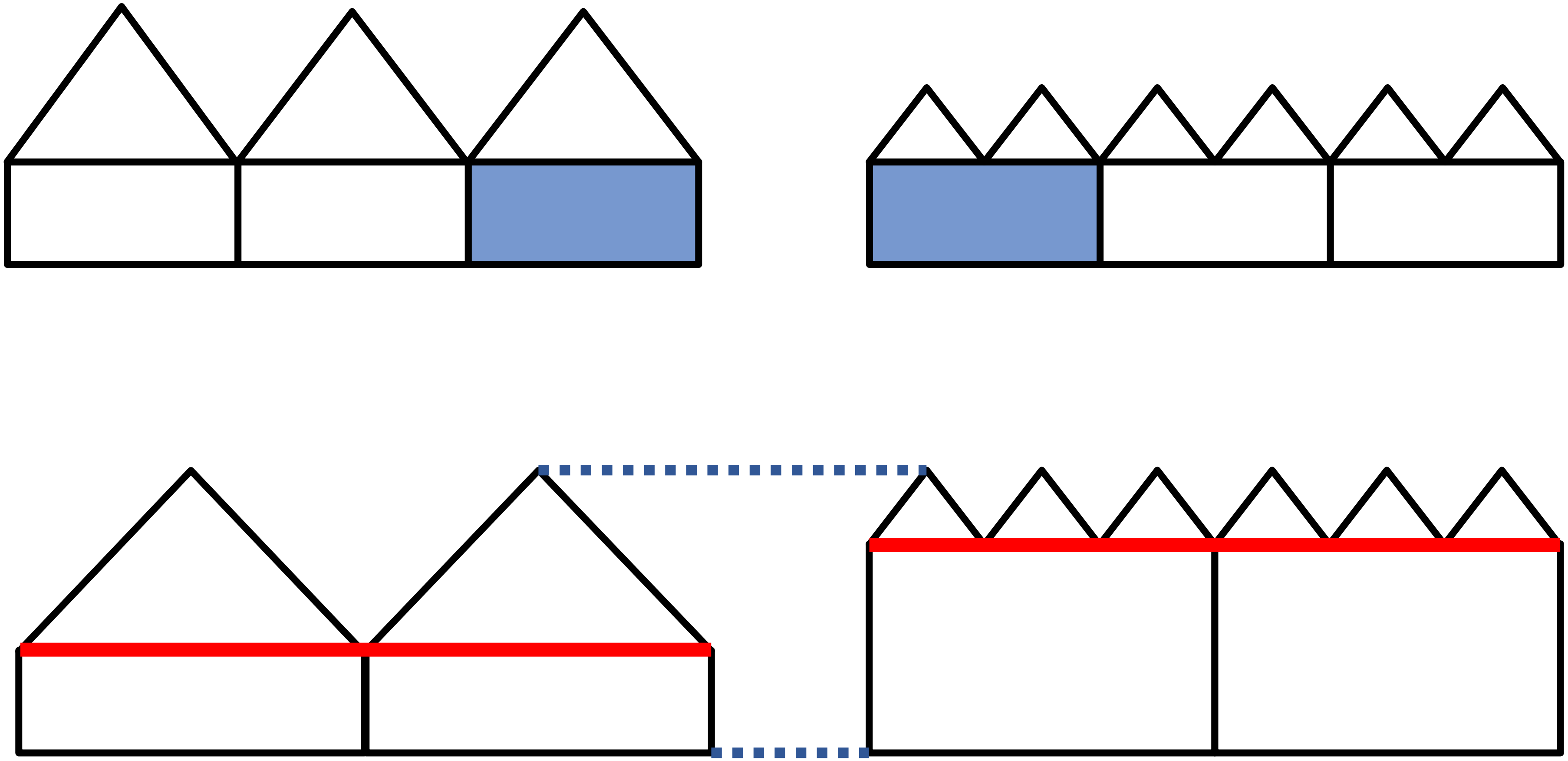
- Not each roof supported by sidewall structures
- each roof has the same width, independent of greenhouse-ground-area
- Static load of roofs only small in scale and effected area
    - Highly flexible building sizes (width & length)
    - taller sidewalls unproblematic


http://www.horconex.nl/en/Greenhouses/Venlo-greenhouse

WIDE SPAN AND VENLO



WIDE SPAN AND VENLO



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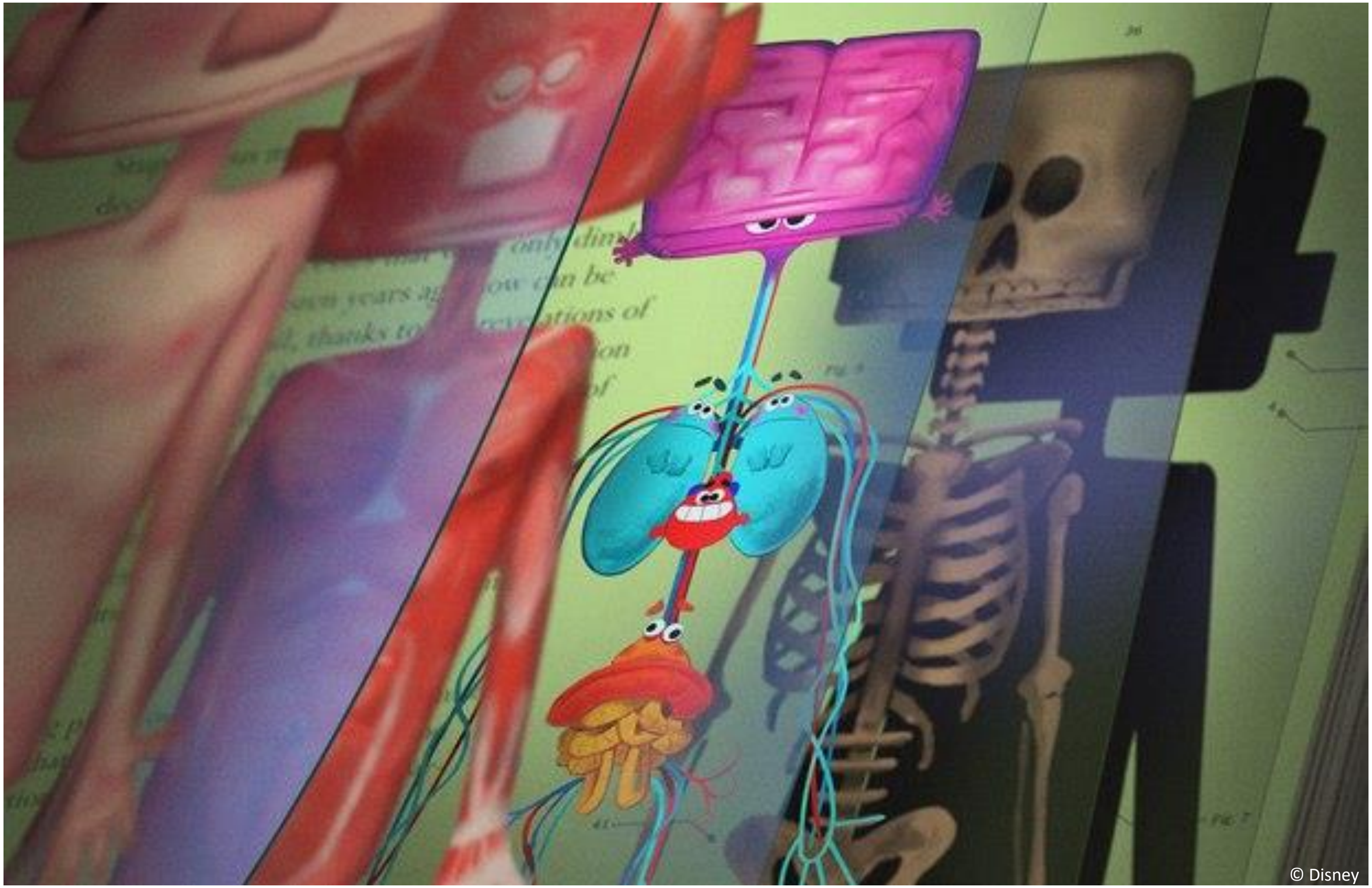


INNER WORKINGS OF A GREENHOUSE

SCREENS


http://www.floraldaily.com/article/2595/Orchid-growers-install-triple-screen


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


http://www.hortidaily.com/article/8645/Asia-Light-diffusion-screens-gaining-popularity-amongst-Chinese-growers

SCREEN FABRIC – DAYSCREEN - NIGHTSCREEN

VENTILATION

Hochschule Geisenheim University

sidewall | roof

free


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


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

forced


https://gothicarchgreenhouses.com/instructorpackages.html


http://www.vittetoe.com/v-flo-fan

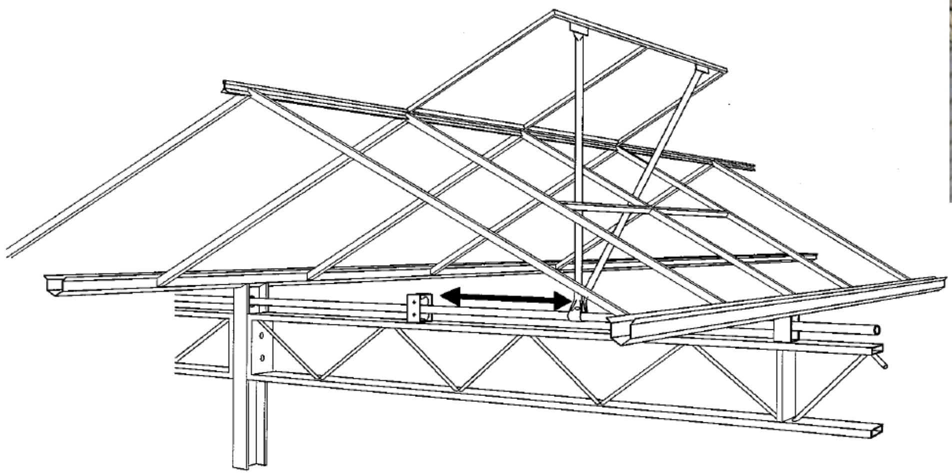
VENTILATION WITH FLEXIBLE COVER MATERIAL

VENTILATION SOLID COVER MATERIAL

VENTILATION MECHANISM

https://fullbloomlightdep.com/product/gothic-blackout-greenhouse-titan-series/

https://www.teksupply.com/contractor/supplies/cat1;ts_greenhouses_accessories-ts_greenhouse_accessories-ts_vent_openers;ts_side_wall_curtain.html



Von Elsner et al., 2000

HEATING

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

https://www.northernpolytunnels.co.uk/commercial-range/greenhouse-hea[illegible]tml

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

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

DIRECT AIR HEATING

- easy to install, easy to remove
- relatively low efficiency
- temperature gradients likely
- CO_2-enrichment possible (gas burner)

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

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- 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


https://www.kpbs.org/news/2015/dec/21/san-diego-aquaponics-farm-gets-bigger/

VERTICAL GARDENING
ALGAE FARMS

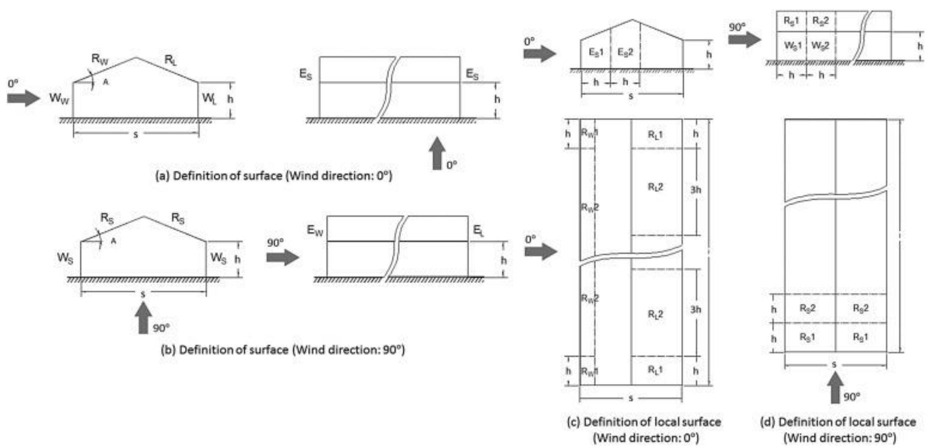
- Still new
- not commercially viable on broad scale
- Mostly lettuce and small leafy plants

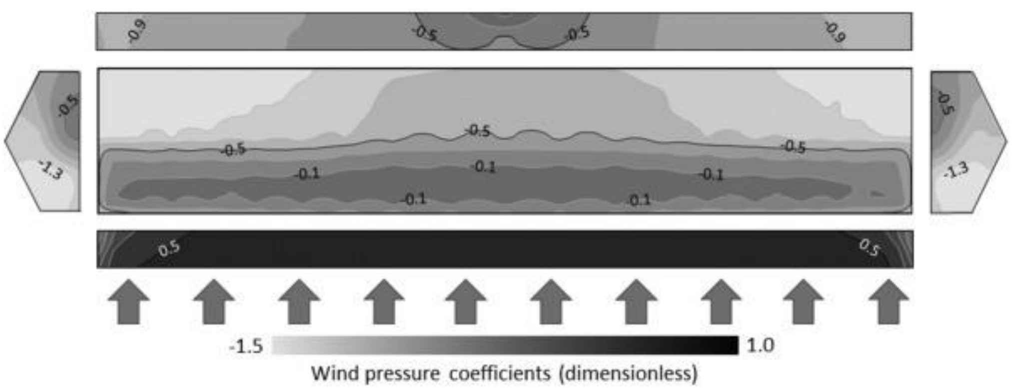
https://www.gardenandgreenhouse.net/articles/greenhouse-articles/vertical-gardens-greenhouse/

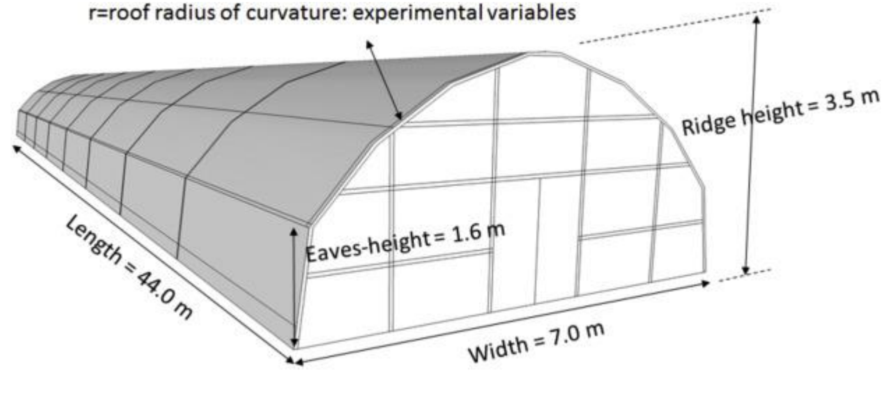
- even fewer examples than V.G.
- used for biotechnological products produced by genetically modified algae

https://es-lab.de/wp/studentische-arbeiten-und-projekte/projekte/iot-steuerung-fuer-die-algenfarm/

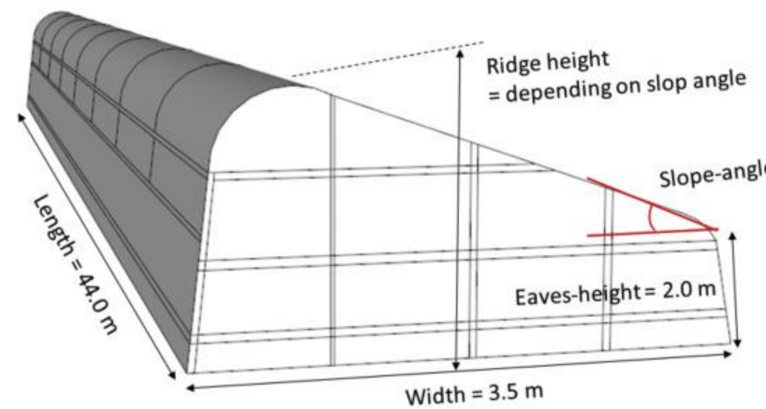
STATICS CONCERNS AND NORMS







(a) Peach-type greenhouse



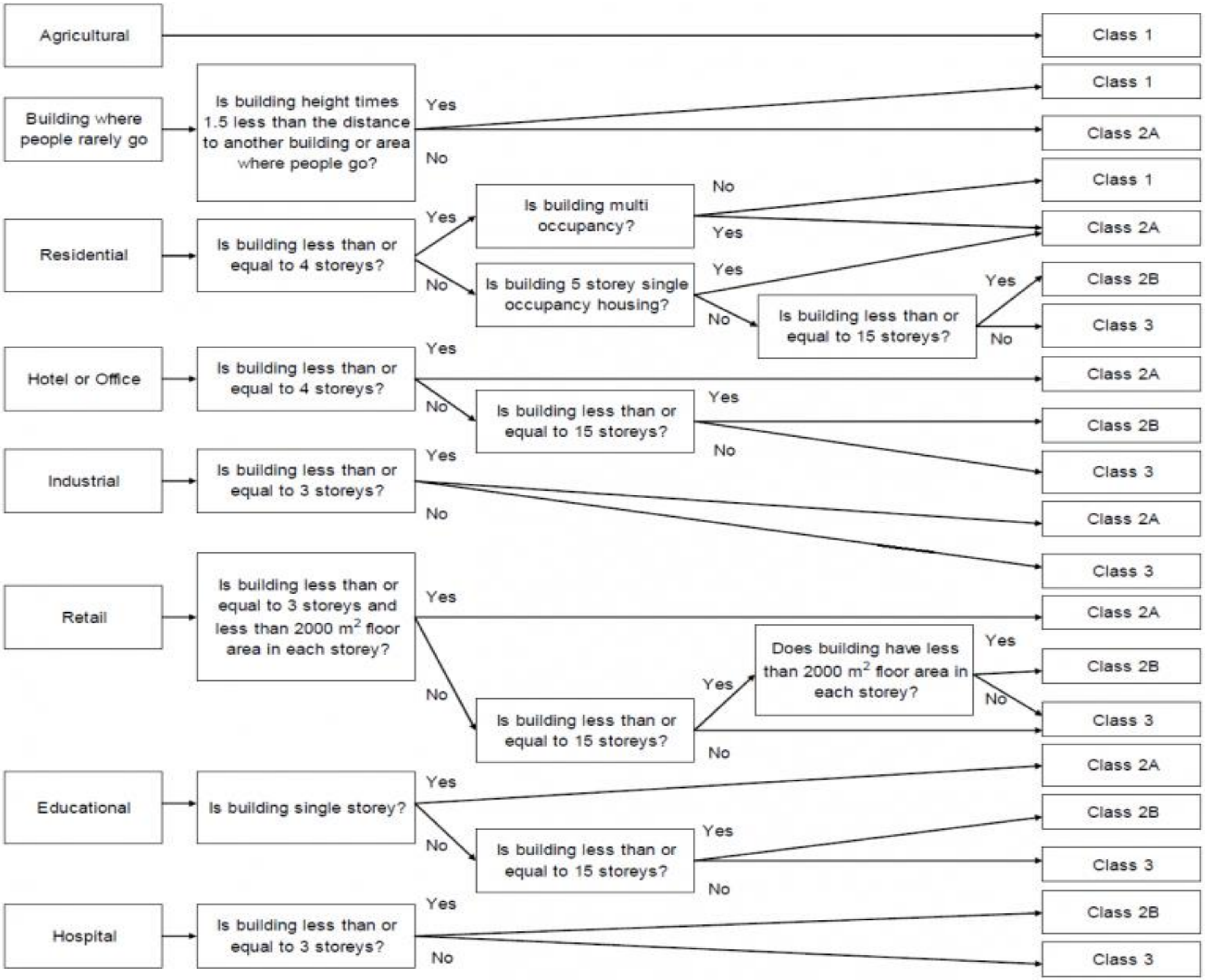
(b) mono-span-type greenhouse

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 pubic, no traffic area
- Same for Earthquake safety : low risk = low importance factor

CONSEQUENCE CLASS



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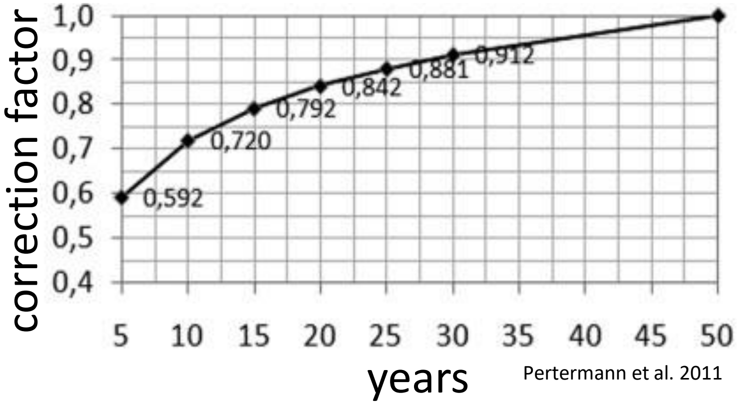
<u>planned</u> life span of greenhouses

(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

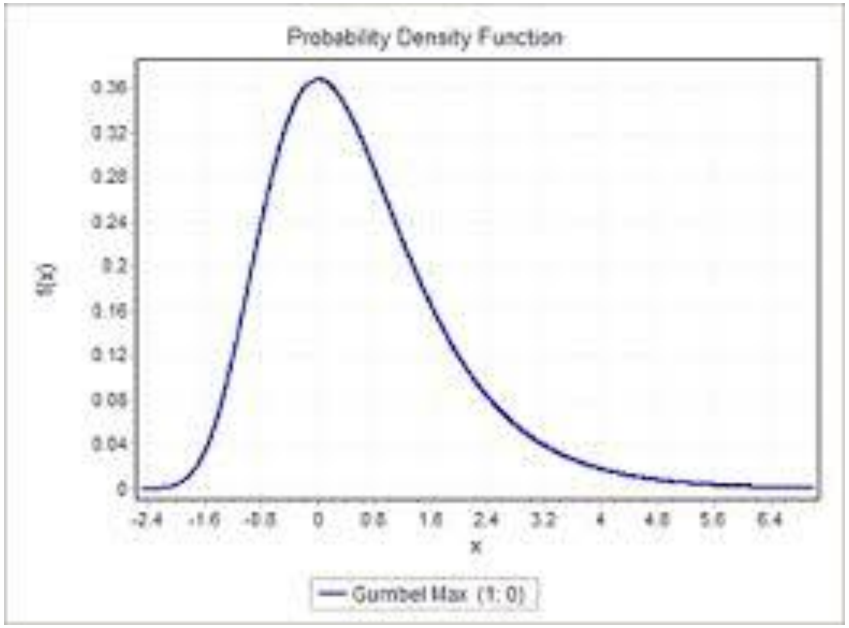


Pertermann et al. 2011

LOADS TO CONSIDER

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/HydroII_Sum17.html

http://www.nipgroup.com/blogs/programs/tag/greenhouse/

Pertermann et al. 2011

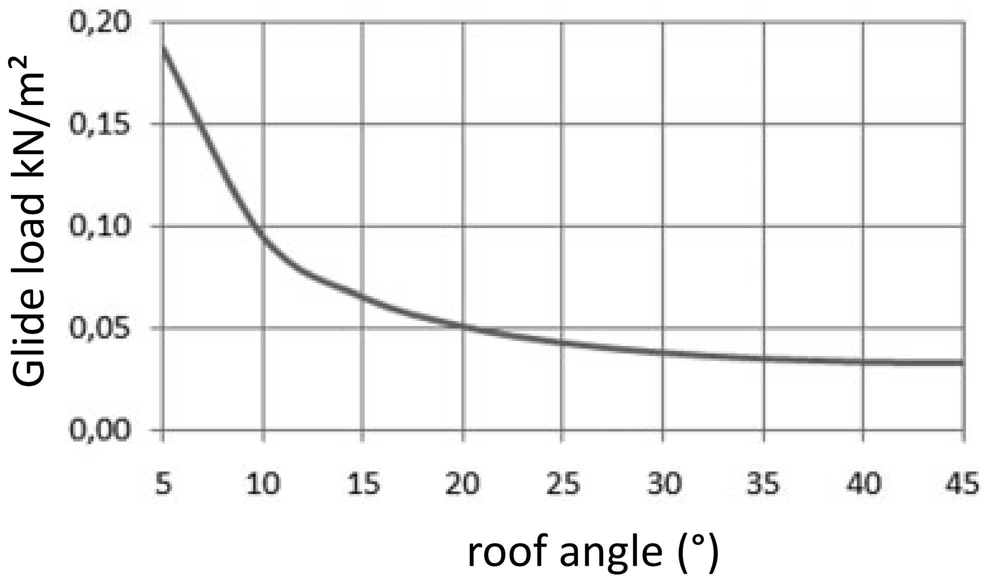
Hochschule Geisenheim University

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

SNOW LOAD



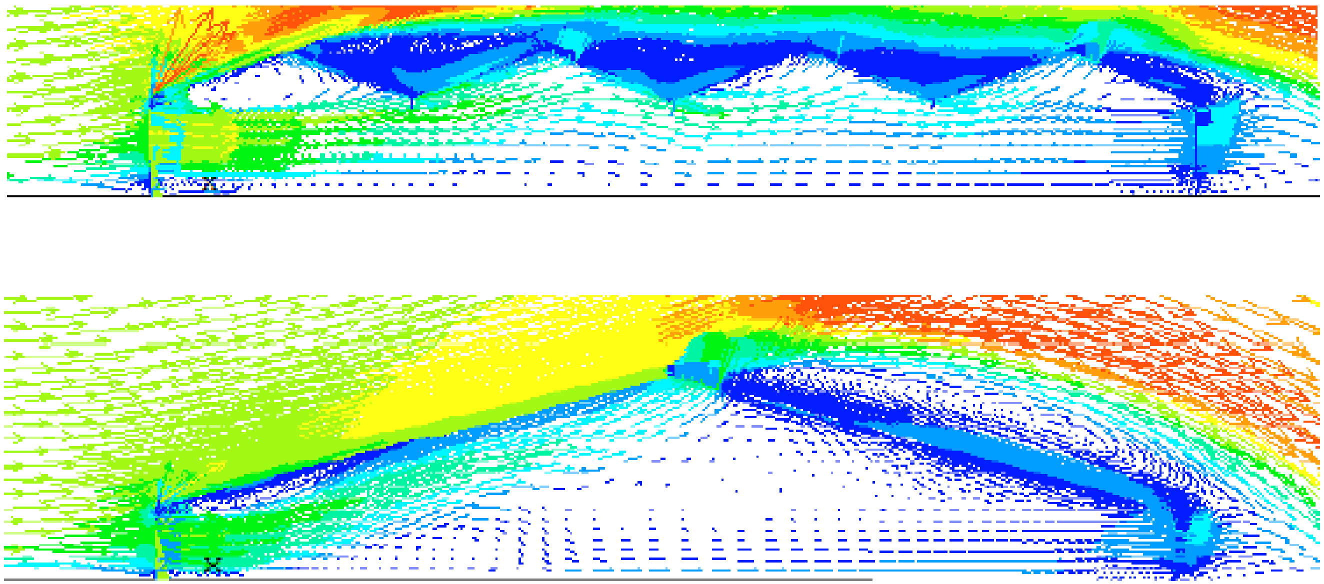
And also:

- 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

Pertermann et al. 2011

WIND LOAD

In Greenhouses with solid hull material less of a problem since thermal expansion dampeners can dampen wind pressure as well



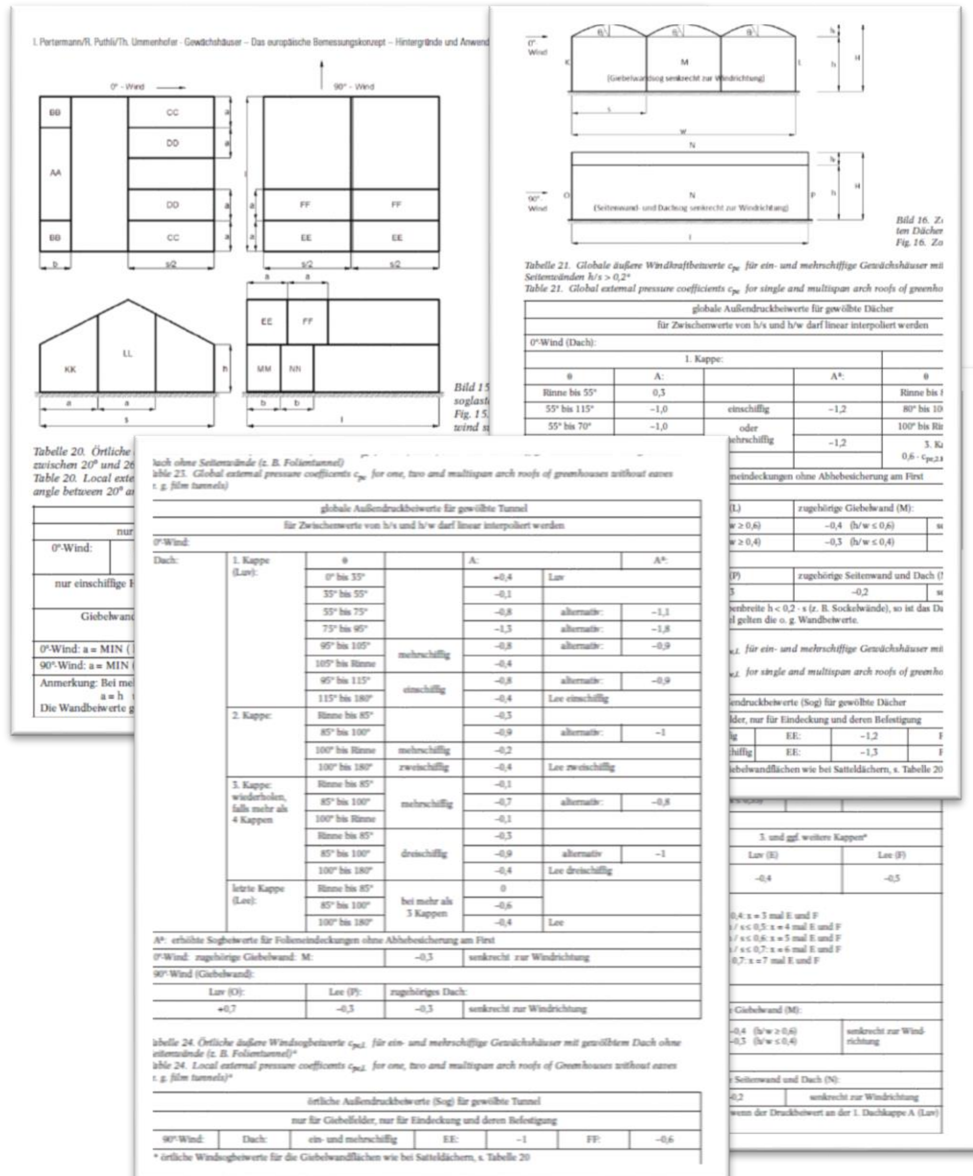
WIND LOAD

- Height of terrain
- Roughness of terrain
  - buildings, vegetation
- Topography
  - cliffs, hills
- Turbulence intensity
  - gusts

Pertermann et al. 2011

WIND LOAD

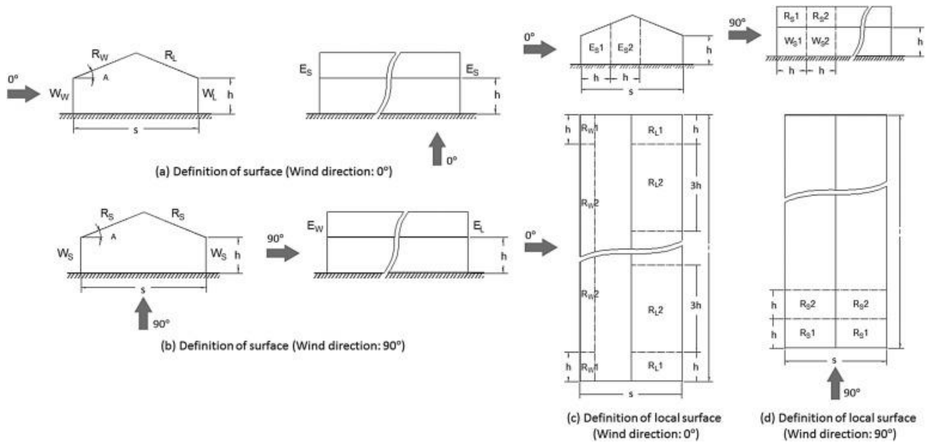
- Lifespan
  - Gumbel
- structure specific variables
  - Tables, lot's of Tables
- Pressure / suction on openings
  - Vents

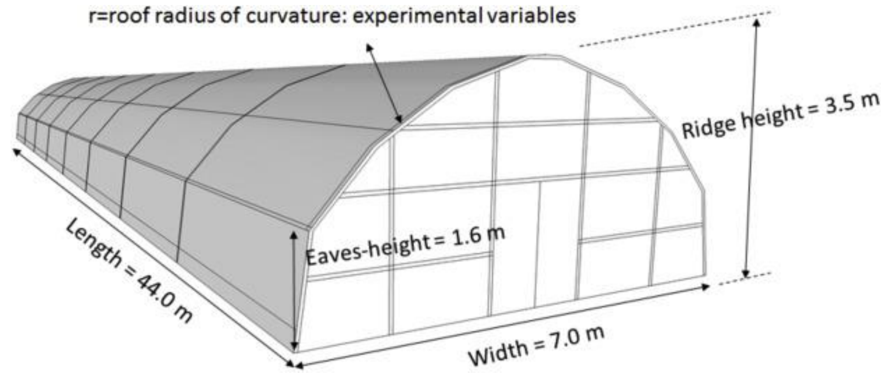


Pertermann et al. 2011

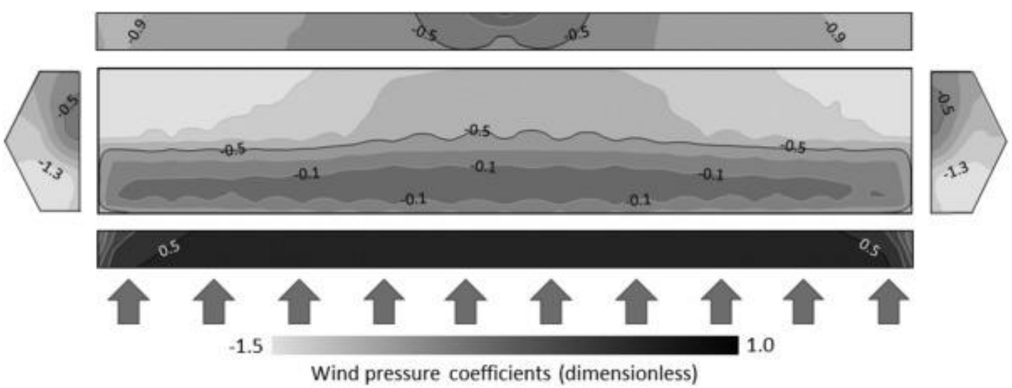
http://www.uni-kassel.de/fb14/geohydraulik/Lehre/Hydrologie_II/HydroII_Sum17.html

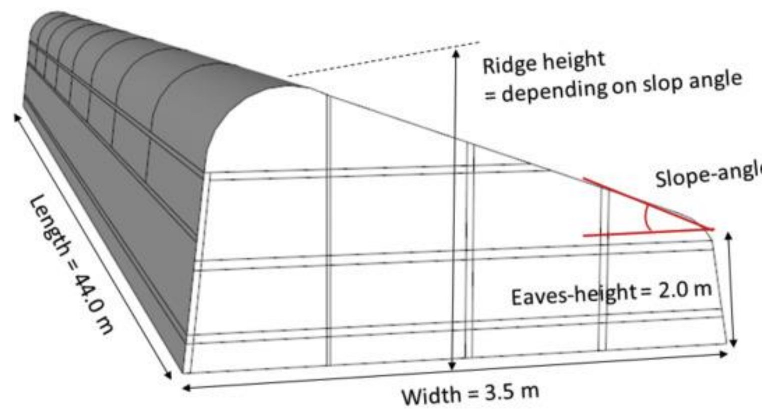
WIND PRESSURE





(a) Peach-type greenhouse





(b) mono-span-type greenhouse

Kyeong-seok Kwon et al. 2016

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/

Hochschule Geisenheim University

ALSO: CLIMATE CHAMBERS

LITERATURE

- **K. Kyeong-seok; K. Dong-woo; K. Rack-woo; H. Taehwan; L. In-bok (2015) :** “Evaluation of wind pressure coefficients of single-span greenhouses built on reclaimed coastal land using a large-sized wind tunnel”. *Biosystems Engineering,* Volume 141, Pages 58-81
- **B. von Elsner; D. Briassoulis; D. Waaijenberg; A. Mistriotis; Chr. von Zabeltitz; J. Gratraud; G. Russo; R. Suay-Cortes (2000):** “Review of Structural and Functional Characteristics of Greenhouses in European Union Countries, Part II: Typical Designs”. *J. agric. Engng Res.*, Volume 75, Pages111-126
- **I. Pertermann; R. Puthli; T. Ummenhofer (2011):** “Gewächshäuser – Das europäische Bemessungskonzept – Hintergründe und Anwendung“, *Stahlbau*, Volume 80, Issue 8, Pages: 572 – 599
- **J.F.J. Max; U. Schurr; H.-J. Tantau; U.N. Mutwiwa; T. Hofmann; A. Ulbrich (2012):** “Greenhouse Cover Technology”, *Horticultural Reviews*, Volume 40, Pages: 259-396
- **E. Rico-Garcia, I.L. Lopez-Cruz, G. Herrera-Ruiz, G.M. Soto-Zarazua and R. Castaneda-Miranda (2008):** ”Effect of Temperature on Greenhouse Natural Ventilation under Hot Conditions: Computational Fluid Dynamics Simulations”. *Journal of Applied Sciences,Volume 8, Pages 4543-4551.*

GLASS AND SUPPORTING STRUCTURE

- metal strut needs to be build according to tensile strength of glass
- overhead minimum bending tensile strength for 4mm float glass: 14,5 N/mm^2