Controlled Environment Systems ABE 483/583

Dr. Gene A. Giacomelli
Professor & Director Controlled Environment Agriculture Center
Department of Agricultural and Biosystems Engineering
Shantz Building, Room 504, Ph: 520 621-1412
and
CEA Building, Room 101, 1971 E. Roger Road, Ph: 520 626-9566
giacomel@ag.arizona.edu

Lecture #3 Structure Design Loadings

Reading: Hannan, Chapter 2 Structures: Locations, Styles, Covers
Specifically: pps 36-50; 63-69

Useful conversions:
1 lb ft^{-2} = 4.88 kg m^{-2}
1 MPH = 1.46 ft s^{-1} = 0.45 m s^{-1}

Design Standards from NGMA and ASAE [ngma.com; asae.org]

National Greenhouse Manufacturers Association Standard for Design Loads in Greenhouse Structures, from NGMA Standards, 1996. These standards **define the Design Loads**, and outline the **procedures for their calculation**.

Combination of Loads

Dead + Live + Wind + Snow

Dead Load -- the weight of all permanent construction including walls, roofs, glazing materials, hanging or supported plants, and fixed service equipment supported by the structure.

Fixed service equipment -- heating, ventilating, cooling systems, shading, energy conservation electrical and lighting systems, watering and humidification systems

Live Load -- temporary loads produced by the use and occupancy of the greenhouse. Exterior live loads can be workman, or temporary equipment [scaffolding]. Interior live loads can be anything hung from the structure for short periods of time. Items imposed on the structure for a continuous period of 30 or more days must be considered a dead load.

Note: Live loads do not include wind, snow or dead loads!

Maximum allowable live load is 15 lb ft^{-2} or 73 kg m^{-2}
Minimum live load is 5 lb ft^{-2} or 24.5 kg m^{-2}

Concentrated Live Load

All roof members should be capable of supporting a Concentrated Live Load of 100 lbs or 45.5 kg applied downward and normal to the roof surface at their midspan.

The bottom chord of a roof truss should be capable of supporting a Concentrated Live Load of 100 lbs or 45.5 kg applied at any point along their length.

Wind Load -- loadings due to wind forces on greenhouse glazing. The glazing transfers the load to the structural connections that attach the glazing to the secondary members [purlins], which transfer the load to the main wind-force resisting system [superstructure], and then to the foundation components of the greenhouse.

Order of force transfer:

glazing→glazing connectors→secondary members→primary members→ foundation→earth

Main wind-force resisting system [superstructure] -- primary greenhouse structural elements [roof trusses, supporting columns, rigid frames, braced frames, etc] which transfer wind loads applied to the glazing through the connectors and secondary structural members of the greenhouse to the foundation.

In general, greenhouses should be designed to withstand an 80 mile $hour^{-1}$ or 36 m s^{-1} wind from the direction which will produce the greatest loads.

Minimum design wind load for the superstructure is 10 lb ft^{-2} or 49 kg m^{-2}

The Design Pressure (P) is defined as the equivalent static pressure to be used in the determination of wind loads on greenhouses. The pressure is assumed to act in a direction normal to the surface under consideration, either as a pressure directed towards the surface [positive value], or a a suction directed away from the surface [negative value]. In calculation of design wind loads for components and glazing of greenhouses, the pressure difference between opposite faces must be considered, which is the difference of the windward and leeward forces. Forces act either inward or outward and normal to the surface. [See Fig. 5-5, pg 6 from NGMA below]

Wind load design pressures can be calculated from equations of Table 5.1, pg 4, NGMA.

<u>Design Pressure for the main wind-force resisting system:</u>

[from Table 5.1, pg 4, NGMA]

$P = q_z(GC_p) - q_h(GC_{pi})$ [psf, pounds per square foot]

Once pressure loads are determined for each section of the structure, then they can be applied to the structure as a whole, in order to evaluate the overall forces caused by the wind loads on the structure.

The structure must then resist these maximum forces.

Look at the above equation as it is broken into its 2 parts:

P = [External loads] - [Internal Loads]

where 'external' refers to the wind loads caused on the outside of the structure, and 'internal' refers to the loads on the inside of the structure caused indirectly by the external wind loads. Remember that high velocity equals low pressure, therefore a negative pressure [or vacuum] can be caused inside the greenhouse by the outside winds.

Consider these loads for each wall or roof

$= [q_z (GC_p)] - q_h(GC_{pi})]$ for windward wall

$= [q_h (GC_p)] - q_h(GC_{pi})]$ for each leeward wall and roof sections where: [see drawing of greenhouse, page 6]

q: q_z, [velocity pressure] for windward wall evaluated at the height z above the ground

q_h, [velocity pressure] for leeward wall, sidewall, and roof evaluated at the mean roof height (h), or defined as velocity pressure at height z = h (psf)

G: [gust response factor] given in Table 5.4

Cp: [external pressure coefficient], given in Table 5.5 and 5.7

(GC_{pi}): [product of gust response factor & internal pressure coefficient], in Table 5.8

<u>Design Pressure for components and glazing:</u>

$$P = q_h(GC_p) - q_h(GC_{pi})$$ [psf, pounds per square foot]

where:

q_h: [velocity pressure] evaluated at the mean roof height (h); (psf); evaluated using 'Exposure C' for all terrains

(GC_p): [product of gust response factor & external pressure coefficient], given in Tables 5.6A, 5.6B and 5.7

(GC_{pi}): [product of gust response factor & internal pressure coefficient], given in Table 5.8

also, b: horizontal dimension of greenhouse measured normal to wind direction [ft]

d: horizontal dimension of the greenhouse measured parallel to the wind direction [ft]

h: mean roof height [ft]; use h = eave height for roofs with slope of less than 10^o

Velocity Pressure [q_z] can be calculated at height z from:

$$q_z = 0.00256\, K_z\, (IV)^2$$ [psf, pounds per square foot]

where:

V: [windspeed MPH, miles per hour], given in Fig. 2-35 Hannan, pg 39, or typically assumed as an 80 mile $hour^{-1}$ or 36 m s^{-1}

I: [importance coefficient], given in Table 5.2; I ~ 0.95 – 1.05

K_z : [velocity exposure coefficient at height z], given in Table 5.3

See Hannan, Fig. 2-35, pg 39 for Wind speed map for U.S.

Snow Load

<u>For flat roof greenhouses:</u>

$$P_f = C_{tg}\, C_c\, IP_g$$

where:

P_f : flat roof design snow load [psf]
C_{tg} : thermal factor; 0.83 for heated GH, 1.0 for unheated or intermittently heated GH
C_c : exposure factor; 0.6 for open-terrain; 0.9 for sheltered areas; 0.7 for all others
I: importance factor; 1.0 for retail & public access GH; 0.8 for all others
P_g: ground snow load [psf]

For sloped roof greenhouses:

$$Ps = Cs\ P_f$$

Heated sloped roof:

$$Cs = 1 - [(\alpha - 15)/55]$$

where α is the angle slope of the roof, and $\alpha > 15$; if $\alpha < 15$, assume flat roof

Unheated sloped roof:

$$Cs = 1 - [(\alpha - 30)/40]$$

where α is the angle slope of the roof, and $\alpha > 30$; if $\alpha < 30$, assume flat roof

Footings -- see A&B, Fig 2.4 Footings

Glazing attachments -- A&B Fig 2-9 Glazing System Fasteners

Figures and Tables

Note that Tables 5.6A & 5.6B are not included below. They will be given as a handout.

Table 5.2

IMPORTANCE COEFFICIENT (I)

Type of Greenhouse	100 Miles or More from Oceanline	Hurricane-Prone Oceanline
Retail Greenhouse with general public access permitted	1.00	1.05
All other greenhouses	0.95	1.00

Notes: (1) Hurricane-prone oceanlines are the Atlantic and Gulf of Mexico coastal areas.

(2) For regions between the hurricane-prone oceanline and 100 miles inland, the importance coefficient, I, shall be determined by linear interpolation.

Table 5.3

VELOCITY EXPOSURE COEFFICIENT (K_z)
z (ft)

Exposure	0-15 ft	20 ft	25 ft
A	0.12	0.15	0.17
B	0.37	0.42	0.46
C	0.80	0.87	0.93
D	1.20	1.27	1.32

Note: Linear interpolation for intermediate values of z is acceptable.

existing construction. Each greenhouse shall be assessed as being located in one of the following exposure categories:

Exposure A: large city centers with at least 50 percent of the buildings having a height in excess of 70 ft. Use of this exposure category shall be limited to those areas for which terrain representative of Exposure A prevails in the upwind direction for a distance of at least one-half mile. Possible channeling effects or increased velocity pressures due to the greenhouse being located in the wake of adjacent buildings shall be taken into account.

Exposure B: urban and suburban areas, well wooded areas or other terrain with numerous closely spaced obstructions having the size of single family dwellings or larger. Use of this exposure category shall be limited to those areas for which terrain representative of Exposure B prevails in the upwind direction for a distance of at least 1500 ft.

Exposure C: open terrain with scattered obstructions having heights generally less that 30 ft. This category includes flat, open country and grasslands.

Exposure D: flat unobstructed coastal areas directly exposed to wind blowing over large bodies of water. This exposure shall be used for those areas representative of Exposure D extending inland from the shoreline a distance of 1500 ft.

5.3.3.2 Exposure Category for Design of Main Wind-Force Resisting System: Wind loads for the design of the main wind-force resisting system in greenhouses shall be based on the exposure categories defined in Section 5.3.3.1.

5.3.3.3 Exposure Category for Design of Components and Glazing: Components and glazing for greenhouses shall be designed on the basis of Exposure C.

Table 5.4

GUST RESPONSE FACTOR (G)
h (ft)

Exposure	0-15 ft	20 ft	25 ft
A	2.36	2.20	2.09
B	1.65	1.59	1.54
C	1.32	1.29	1.27
D	1.15	1.14	1.13

Note: Linear interpolation for intermediate values of h is acceptable.

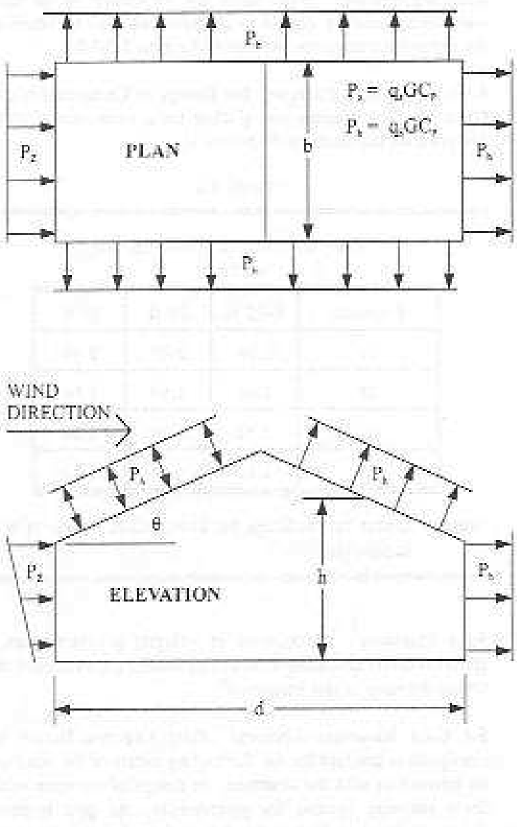
5.3.4 Shielding: Reductions in velocity pressures due to apparent direct shielding afforded by buildings, structures and terrain features is not permitted.

5.4 Gust Response Factors: Gust response factors are employed to account for the fluctuating nature of the wind and its interaction with the structure. In design of the main wind-force resisting system for greenhouses, the gust response factor, G, is taken from Table 5.4 evaluated at the structure's mean roof height, h. In design of the components and glazing for greenhouses, the gust response factors are combined with the pressure coefficients to yield values of (GC_p) and (GC_{pi}) as given in Tables 5.6 through 5.8.

5.5 Pressure Coefficients: Pressure coefficients for greenhouse structures and their components and glazing are given in Tables 5.5 through 5.8. In the tables, + and - signs signify pressures acting toward and away from the surfaces, respectively.

Table 5.5

EXTERNAL PRESSURE COEFFICIENTS
FOR AVERAGE LOADS ON MAIN
WIND - FORCE RESISTING SYSTEM



WALL PRESSURE COEFFICIENTS C_p

SURFACE	d/b	C_p
WINDWARD WALLS	ALL VALUES	0.8
LEEWARD WALLS	0 -1 2 ≥ 4	-0.5 -0.3 -0.2
SIDE WALLS	ALL VALUES	-0.7

ROOF PRESSURE COEFFICIENTS C_p

	WINDWARD							LEE-WARD
WIND DIRECTION	h/d	ANGLE θ DEGRESS						
		0	10-15	20	26.6	30	40	
NORMAL TO RIDGE	≤ 0.3	-0.7	0.2* -0.9*	0.2	0.27	0.3	0.4	-0.7 for all values of h/d and θ
	0.5	-0.7	-0.9	-0.75	-0.39	-0.2	0.3	
	1.0	-0.7	-0.9	-0.75	-0.39	-0.2	0.3	
	≥ 1.5	-0.7	-0.9	-0.9	-0.9	-0.9	-0.35	
PARALLEL TO RIDGE	h/b or h/d ≤ 2.5	-0.7						-0.7
	h/b or h/d > 2.5	-0.8						-0.8

*Both values of C_p shall be used in assessing load effects.

NOTES: (1). Refer to Table 5.7 for arched roofs, Table 5.6A and 5.6B for components and glazing, and Table 5.8 for internal pressure.
(2). For G, use appropriate value from Table 5.4.
(3). Linear interpolation may be used to obtain intermediate values of θ, h/b, h/d, and d/b not shown.

Table 5.6A

EXTERNAL PRESSURE COEFFICIENTS FOR LOADS
ON COMPONENTS AND GLAZING (WALLS)

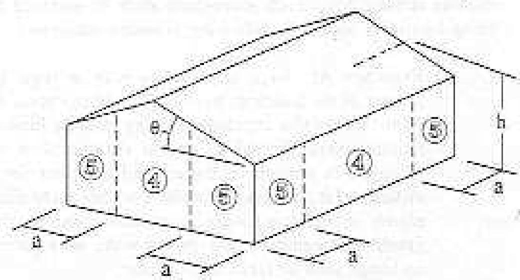


Figure 5.1 Basic Wind Speed (MPH)

Table 5.7

EXTERNAL COEFFICIENTS (C_p) FOR ARCHED ROOFS

Type of Roof	Rise-to-Span Ratio	Windward Quarter	Center Half	Leeward Quarter
Roof on elevated structure	0<r<0.2 0.2≤r<0.3* 0.3≤r≤0.6	-0.9 (1.5r-0.3) (2.75r-0.7)	(-0.7-r) (-0.7-r) (-0.7-r)	-0.5 -0.5 -0.5
Roof springing from ground level	0<r≤0.6	1.4r	(-0.7-r)	-0.5

* When the rise to span ratio is (0.2≤r≤0.3), alternate coefficients given by (6r-2.1) shall also be used for the windward quarter.

Notes:

1. Values listed are for determination of average loads on main wind force resisting system.

2. For components and glazing at roof perimeter use external pressure coefficients in Table 5.6B with Θ based on spring-line slope and q_h based on Exposure C.

3. For components and glazing in roof areas away from the perimeter use the external pressure coefficients of this table multiplied by 1.2 for (GC_p) and q_h based on Exposure C.

4. Definition of terms as follows:

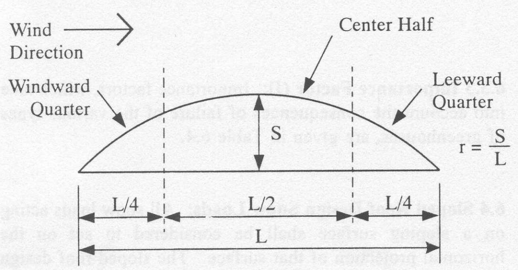


Table 5.8

INTERNAL PRESSURE COEFFICIENTS (GC_{pi})

Conditions	(GC_{pi})
Percentages of openings in one wall exceeds that of all other walls by 10% or more and openings in all other walls do not exceed 20% of respective wall area	+0.75 and -0.25
All other cases	±0.25

6.0 SNOW LOAD

6.1 General: Provisions for the determination of snow loads on greenhouse structures are described in the following subsections. The provisions apply to the calculation of snow loads for both continuously heated greenhouses and for intermittently heated or unheated greenhouses.

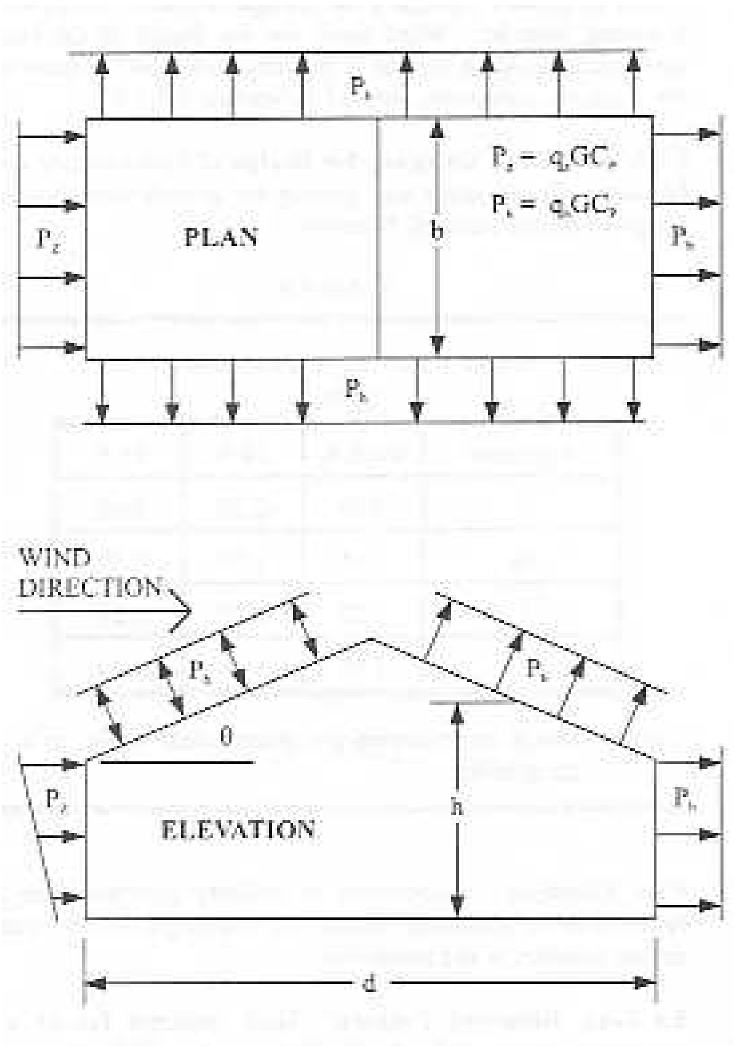
6.1.1 Definitions: The following definitions apply only to the provisions of Section 6, SNOW LOADS.

Thermal Resistance (R): A factor which measures a material's resistance to the transmission of heat. The smaller the R value, the greater the amount of heat a material will transmit.

Continuously Heated Greenhouses: A production or retail greenhouse with a constantly maintained temperature of 50 degrees F or more during winter months. Such greenhouse must also have a maintenance attendant on duty at all times or an adequate temperature alarm system to provide warning in the event of a heating system failure. In addition, the greenhouse roof material must have a thermal resistance (R) less than 2.0.

Intermittently Heated or Unheated Greenhouse: Any greenhouse that does not meet the requirements of a continuously heated single or double glazed greenhouse.

6.2 Ground Snow Loads: Ground snow loads, P_g, to be used in the determination of design snow loads for roofs of greenhouses are given in Figs. 6.1, 6.2, and 6.3 for the contiguous United States. In some areas, the amount of local variation in snow loads is so extreme as to preclude


P_h
P_z = q_zGC_p
P_h = q_hGC_p
P_z
PLAN
b
P_h
P_h
WIND
DIRECTION
P_z
P_h
θ
P_z
ELEVATION
h
P_h
d