NATIONAL GREENHOUSE MANUFACTURERS ASSOCIATION STANDARDS FOR DESIGN LOADS IN GREENHOUSE STRUCTURES

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FOREWARD

The National Greenhouse Manufacturers Association, NGMA, is a voluntary association of prominent U.S. greenhouse manufacturers. NGMA's objectives and activities are concerned not only with benefits to its membership but to the entire commercial growing industry. The symbiotic relationship between greenhouse suppliers and growers is unique in the buyer-seller world.

During the past three decades, NGMA members have been leaders in the introduction of new and improved structural components, materials, and systems. They have developed or have caused others to develop improved glazing materials, heating and cooling equipment, and environment control systems.

NGMA has consistently worked to meet the needs of the growing industry, as the needs have evolved. Many of the features standard to greenhouse installations today were pioneered by NGMA member companies in response to these needs. NGMA members address themselves to current issues affecting growers.

NGMA members are strong competitors, providing a healthy market situation. Yet on behalf of themselves and their markets, they recognize mutuality of interest in such matters as establishing acceptable greenhouse construction standards. They work together solidly and harmoniously in pursuit of objectives which result in lasting benefits to both the greenhouse seller and the greenhouse buyer.

These standards were developed through the unsolicited efforts of the various members and represent the recommended standards of performance for quality greenhouse construction and design for climate control. However, they are purely voluntary and are not mandatory on any firm for compliance to maintain membership in the Association nor are there any other covenants. It is believed that the voluntary usage of these standards will result in quality perfor-

HISTORY OF NGMA STANDARD

On November 5, 1968, NGMA adopted its first structural standard. Seven years later on November 12, 1975, a revised version of the first standard was adopted. Both these original standards were brief documents which defined loads to be used in the design of greenhouse structures throughout the country. The load values and requirements of the standard were based on years of experience in manufacturing and construction of greenhouses, on consideration of characteristics that are unique to greenhouse structures, and on the history of successful structural performance of thousands of greenhouses constructed during the past 50 years.

Following adoption of the revised standard in 1975, NGMA made an effort to have its requirements included in several recognized building codes. However, it was found that specific NGMA requirements adopted by each of these codes often varied. As a result, NGMA submitted its standard to the American National Standards Institute (ANSI) for incorporation into ANSI A58.1, “Building Code Requirements for Minimum Design Loads in Buildings and Other Structures”. In a draft of ANSI A58.1 dated March 10, 1982, most of the NGMA requirements were covered either as part of the code itself or as part of the appendix to the code.

In a continuing effort to improve and further standardize greenhouse design and construction, NGMA has developed this current expanded structural load standard. The standard is based on the currently proposed ANSI A58.1 and in fact follows the same notation, and much of the same wording. However, any ANSI requirements that do not apply specifically to greenhouse-type structures have been deleted. In addition, several sections, while keeping in line with the ANSI intent, have been modified and simplified. In 1996, Section 6.0 snow load, was revised to follow the notation and wording of the BOCA National Building Code, 1993.

1.0 GENERAL

1.1 Scope: This standard provides load requirements for design of greenhouse structures and their components. The loads specified herein are to be used in conjunction with the allowable stresses recommended in current design specification for aluminum, steel, wood, glass, concrete or any other conventional structural material used in the construction of greenhouses.

1.1.1 Definitions: The following definitions are intended to apply only to greenhouse structures and their components.

Free-Standing Greenhouse: an independently erected greenhouse set totally apart from other buildings and structures. Free-standing greenhouses are usually symmetrical about a longitudinal centerline (even-span) with either a pitched or an arched roof.

Attached Even-Span Greenhouse: a greenhouse structure similar to a free-standing greenhouse except that one or both gable ends or sides are eliminated and are attached to an adjacent structure.

Lean-to Greenhouse: a greenhouse structure which depends on its attachment to another building for much of its support. A lean-to greenhouse appears as a free-standing greenhouse bisected in half along its longitudinal centerline with the missing side provided by the building against which it is supported.

Gutter-Connected Greenhouse: a series of two or more free-standing greenhouses joined together at their eave line. A gutter is provided at the common eave of adjacent greenhouses to allow collection and run-off of rain or melting snow. Usually the common sides of two adjacent gutter-connected greenhouses are omitted to provide greater uninterrupted interior growing space.

Gable Ends: the two exterior walls of a free-standing greenhouse which are oriented perpendicular to the longitudinal axis of the greenhouse.

Sides: the two exterior walls of a free-standing greenhouse which are oriented parallel to the longitudinal axis of the greenhouse.

Eave: the intersection of the roof and the side of a typical greenhouse.

Hobby House: a greenhouse used by an individual or family for growing flowers and plants as a hobby. A hobby house may be free-standing, attached even-span or lean-to.

Production Greenhouse: a greenhouse used for growing large numbers of flowers and plants on a production basis or for research. Generally there is no public access to a production greenhouse. Included in this category are privately owned greenhouses used for research purposes.

Retail Greenhouse: similar to a production greenhouse in that it is used for growing large numbers of flowers and plants. However, in a commercial greenhouse, general public access for the purpose of viewing and purchasing the various products is permitted. Included in this category are greenhouses used by colleges or universities for teaching purposes or for research.

Glazing Material: any rigid material such as glass or fiberglass, rigid plastics, or any flexible plastic material such as polyethylene used to enclose a greenhouse while at the same time permitting the entrance of natural light.

1.1.2 Limitations: This standard applies to free-standing, attached even-span and lean-to greenhouses whose individual foundations are at ground level. Greenhouses constructed on top of other structures, solar domes, skylights and similar greenhouse-type structures are not specifically covered.

1.2 Basic Requirements

1.2.1 Safety: Greenhouse structures and all parts thereof shall be designed and constructed to safely support all loads, including dead load, without exceeding the allowable stresses for the materials from which the greenhouse is constructed.

1.2.2 Serviceability: Greenhouse structures and their components shall have adequate stiffness to limit vertical and transverse deflections, vibrations or any other deformation that may adversely affect their serviceability.

1.2.3 Analysis: Load effect on the individual components and connections of greenhouse structures shall be determined by accepted methods of structural analysis.

1.3 General Structural Integrity: Through accident or misuse, a greenhouse structure capable of safely supporting the required design loads may suffer local damage, i.e., the loss of load resistance in an element or small portion of the structure. In recognition of this, the greenhouse structure shall possess general structure integrity, i.e., the quality of being able to sustain local damage with the structure as a whole remaining stable and not damaged to an extent disproportionate to the original local damage.

1.4 Additions to Existing Structures: When a lean-to or attached even-span greenhouse is added to an existing building, provision shall be made to adequately strengthen the existing structure, where necessary, to withstand existing loads as well as any additional loads imposed on it by the greenhouse.

2.0 COMBINATION OF LOADS

2.1 Combining Loads: Except when applicable codes make other provisions, all loads listed herein shall be considered to act in the following combinations. The governing case shall be that which produces the most unfavorable effects in the structure, foundation, or member under consideration.

(1) D
(2) D + L
(3) D + S
(4) D + W
(5) D + L + W
(6) D + S + W

Where:

D = Dead Load
L = Live Load
S = Snow Load
W = Wind Load

2.2 Load Combination Factors: Allowable stresses may be increased 33% for any of the above combinations that include wind providing the resulting allowable stress does not exceed the yield stress.

2.3 Counteracting Loads: When the effects of design loads counteract one another in a structural member or joint, care shall be taken to ensure adequate safety for possible stress reversals.

3.0 DEAD LOADS

3.1 Definition: The weight of all permanent construction including but not limited to walls, roofs, glazing materials and fixed service equipment.

3.2 Weights of Building Materials: In estimating dead loads for purpose of design, the actual weights of pertinent building materials shall be used. In the absence of definite information, values satisfactory to the authority having jurisdiction shall be used.

3.3 Weight of Fixed Service Equipment: In estimating dead loads for purpose of design, the weight of fixed service equipment such as heating, ventilating and cooling systems, electrical and lighting systems, and watering and humidification systems shall be included whenever it is supported by structural members.

3.4 Special Considerations: Factors that may result in differences between actual and calculated values should be considered when determining dead loads. In addition, any permanent loads such as hanging baskets, planters, etc., that are to be supported by structural members for an extended time period *(Section 4.1)* shall be included as part of the dead load.

4.0 LIVE LOADS

4.1 Definitions: Live loads are temporary loads produced by the use and occupancy of the greenhouse. Live loads do not include wind load, snow load, or dead load. Exterior live loads on greenhouse roofs are the temporary loads workmen and temporary equipment such as scaffolds. Interior live loads are temporary loads imposed on the structure by hanging objects. Any live load shall be considered permanent and therefore included as part of the dead load *(Section 3.4)*if it is imposed on the structure for a continuous period of 30 days or more.

4.2 Minimum Roof Live Load: Pitched and arched greenhouse roofs shall be designed to safely support the minimum live load specified in the following equation or the snow load specified in Section 6, whichever is greater.

$$L = 20 R_1 R_2 \quad 12$$

where L, the minimum live load, is in pounds per square foot of horizontal projection, and R_1 and R_2 are reduction factors determined as follows:

$R_1 = 1.0$ for $A_t \quad 200$
$= 1.2 - 0.001 A_t$ for $200 < A_t < 600$
$= 0.6$ for $A_t \geq 600$

in which A_t is the tributary area in square feet supported by the structural member under consideration;

$R_2 = 1.0$ for $F \leq 4$
$= 1.2 - 0.05 F$ for $4 < F < 12$
$= 0.6$ for $F \geq 12$

in which F is equal to the number of inches of rise per foot for a pitched roof and is equal to the rise to span ratio multiplied by 32 for an arched roof.

4.3 Maximum Roof Live Load: The live load determined by the requirements of Section 4.2 shall be limited to a maximum value of 15 PSF

4.4 Concentrated Loads: All roof members such as purlins, rafters, truss top members, etc., shall be capable of safely supporting a minimum concentrated live load of 100 lbs applied downward and normal to the roof surface at their midspan. In addition, bottom chord panel points of roof trusses shall be capable of safely supporting a minimum concentrated live load of 100 lbs applied at any panel point. See Section C4.4 for further discussion of concentrated loads.

4.5 Partial Loading: The full intensity of the live load applied only to a portion of a greenhouse structure or to a portion of an individual member shall be considered if it produces a more unfavorable effect than the full intensity applied over the entire structure or member.

4.6 Impact Loads: The concentrated live load specified in Section 4.4 includes adequate allowance for ordinary impact conditions.

4.7 Restrictions on Loading: It shall be the responsibility of the greenhouse manufacturer to inform the owner of the live loads for which the greenhouse was designed. It shall then be the responsibility of the greenhouse owner to ensure that a live load greater than that for which the roof or roof supporting members were designed is not placed upon the roof or supporting members.

5.0 WIND LOADS

5.1 General: Provisions for the determination of wind loads on greenhouse structures are described in the following subsections. The provisions apply to the calculation of wind loads for both the main wind-force resisting system and the individual components and glazing of the structure.

5.1.1 Wind Loads During Erection and Construction Phases: Adequate temporary bracing shall be provided to resist wind loading on structural components and structural assemblages of greenhouses during the construction phase.

5.1.2 Overturning and Sliding: The overturning moment due to wind load shall not exceed two-thirds of the dead load stabilizing moment unless the greenhouse structure is anchored to resist the excess moment. When the total resisting force due to friction is insufficient to prevent sliding, anchorage shall be provided to resist the excess sliding force.

5.1.3 Definitions: The following definitions apply only to the provisions of Section 5, WIND LOADS.

Main Wind-Force Resisting System: an assemblage of major structural elements assigned and designed to support the design wind force. The system transfers wind load applied to the components and glazing of the greenhouse to its structural foundation. Such systems include combinations of roof trusses and supporting columns, rigid frames, braced frames, etc.

Components and Glazing: local structural elements which are directly loaded by the wind. In greenhouses, examples of such elements are glass, rigid plastics, or fiberglass glazing materials and the connection devices used to attach these materials to the structure. Secondary members that support the glazing materials and transfer the wind loads to main wind-force resisting system (members such as purlins and lintel beams) should be considered as components.

Importance Coefficient (I): a coefficient to account for hazard to human life and damage to property.

Design Pressure (P): 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 as a suction directed away from the surface (negative value). In calculating the design wind loads for components and glazing the pressure difference between opposite faces of the surface shall be taken into consideration.

5.1.4 Symbols and Notations: The following symbols and notations apply only to the provisions of Section 5, WIND LOADS.

A: Tributary area for determination of wind loads on components and glazing (sq ft)

a: Width of pressure coefficient zone (ft)

b: Horizontal dimension of greenhouse normal to wind direction (ft)

d: Horizontal dimension of greenhouse parallel to wind direction ridge line (ft)

C_p: External pressure coefficient

C_{pi}: Internal pressure coefficient

G: Gust response factor

(GC_p): Product of external pressure coefficient and gust response factor

(GC_{pi}): Product of internal pressure coefficient and gust response factor

h: Mean roof height of greenhouse (ft). Eave height may be used for greenhouses having pitched roofs with slopes of less than 10 degrees.

I: Importance coefficient

K_z: Velocity exposure coefficient at height z

P: Design pressure (psf)

P_h: Design pressure at height z = h (psf)

P_z: Design pressure at height z (psf)

q: Velocity pressure (psf)

q_h: Velocity pressure at height z = h (psf)

q_z: Velocity pressure at height z (psf)

r: Rise to span ratio for arched roofs

V: Basic wind speed (mph)

z: Height above ground level (ft)

θ: Angle of plane of pitched roof (degrees)

5.2 Calculation of Wind Loads:

5.2.1 General: The design wind loads for greenhouse structures as a whole or for individual components and glazing shall be determined by the Analytical Procedure described in Section 5.2.2.

5.2.2 Analytical Procedure: Design wind pressures for greenhouses shall be determined in accordance with the equations in Table 5.1 using the following procedure:

(1) A velocity pressure, q, is determined in accordance with Section 5.3.

(2) A gust response factor, G, is determined in accordance with the provisions of Section 5.4.

(3) Appropriate pressure or force coefficients are selected from Section 5.5.

5.2.2.1 Minimum Design Wind Loading: The wind load to be used in the design of the main wind-force resisting system for greenhouses shall be at least 10 psf.

In the calculation of design wind loads for components and glazing of greenhouses, the pressure difference between opposite faces shall be taken into consideration. The combined design pressure shall be at least 10 psf acting either inward or outward normal to the surface.

Table 5.1

DESIGN WIND PRESSURES (P)

For the main wind-force resisting system:

$$P = qGC_p - q_h\,(GC_{pi})$$

where:

q: q_z for windward wall; q_h for leeward wall and roof

G: given in Table 5.4

C_p: given in Table 5.5 and 5.7

(GC_{pi}): given in Table 5.8

For components and glazing:

$$P = q_h\,(GC_p) - q_h\,(GC_{pi})$$

where:

q_h: evaluated using Exposure C for all terrains

(GC_p): given in Tables 5.6A, 5.6B and 5.7

(GC_{pi}): given in Table 5.8

5.3 Velocity Pressure:

5.3.1 Procedure For Calculating Velocity Pressure: The velocity pressure q_z at height z shall be calculated as follows:

$$q_z = 0.00256\ K_z\ (IV)^2$$

where:

V: given in Fig. 5.1 in accordance with the provisions of Section 5.3.2

I: given in Table 5.2

K_z: given in Table 5.3 in accordance with the provisions of Section 5.3.3

5.3.2 Selection of Basic Wind Speed: The basic wind speeds, V, to be used in determination of design wind loads shall be as given in Fig. 5.1 for the contiguous United States and Alaska. The basic wind speed for Hawaii shall be 80 mph. In no case shall the basic wind speed be less than 70 mph.

5.3.2.1 Special Wind Regions: (See Section C5.3.2.1)

5.3.3 Exposure Categories:

5.3.3.1 General: An exposure category shall be determined for the general region in which the greenhouse is to be constructed. Exposure categories are intended to reflect variations in surrounding ground surface roughness arising from both natural topography and vegetation as well as existing

Table 5.2

IMPORTANCE COEFICIENT (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 eastern 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 5.2

VELOCITY EXPOSURE COEFFICIENT (K_2)
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.

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.

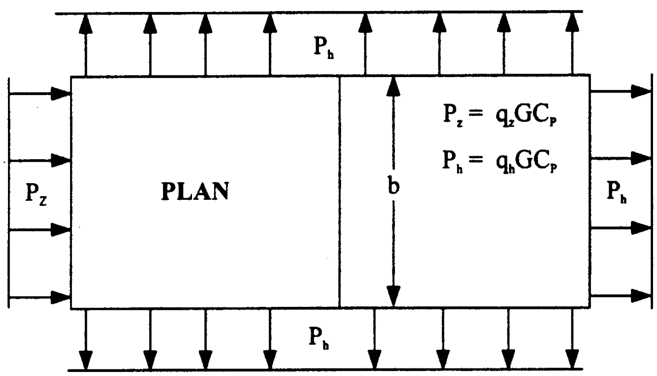
5.3.4 Shielding: Reductions in velocity pressures due to apparent direct shielding afforded by buildings, structures and terrain features is not permitted.

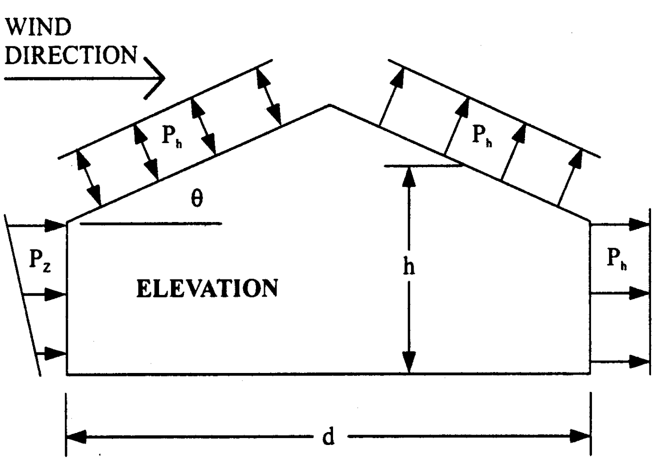
5.4 Gust Response Factors: Gust response factors are employed to account for the fluctuating nature of the wind and its interaction with the structure. In design of the main wind-force resisting system for greenhouses, the gust response factor, G, is taken from Table 5.4 evaluated at the structure's 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.

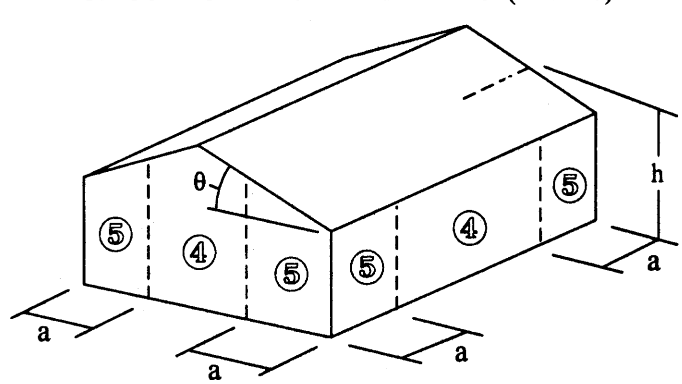
Notes: (1). Refer to Table 5.7 for arched roofs, Table 5.6A and 5.6B for components and glazing, and Table 5.8 for internal pressure.

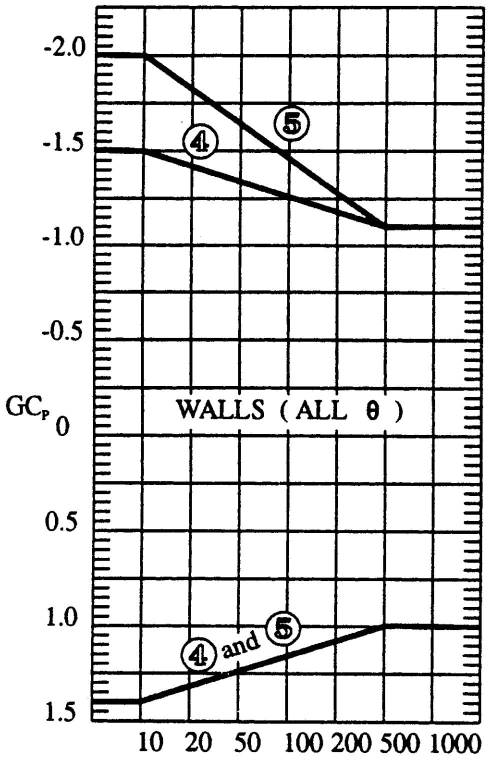
(2). For G, use appropriate value from Table 5.4.

(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)





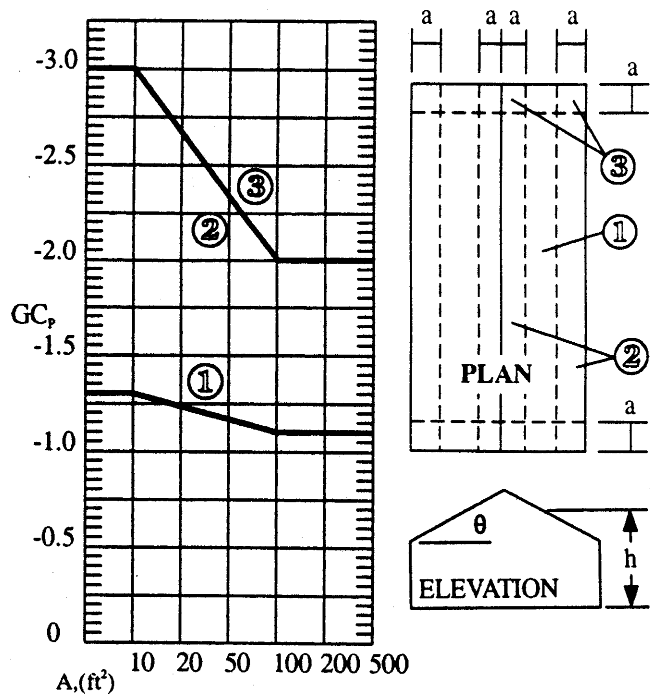
NOTES:

1. Notes apply to both Tables 5.6A and 5.6B

2. Vertical denotes (GCp) to be used with qh.

3. Horizontal scale denotes tributary area, A (ft²)

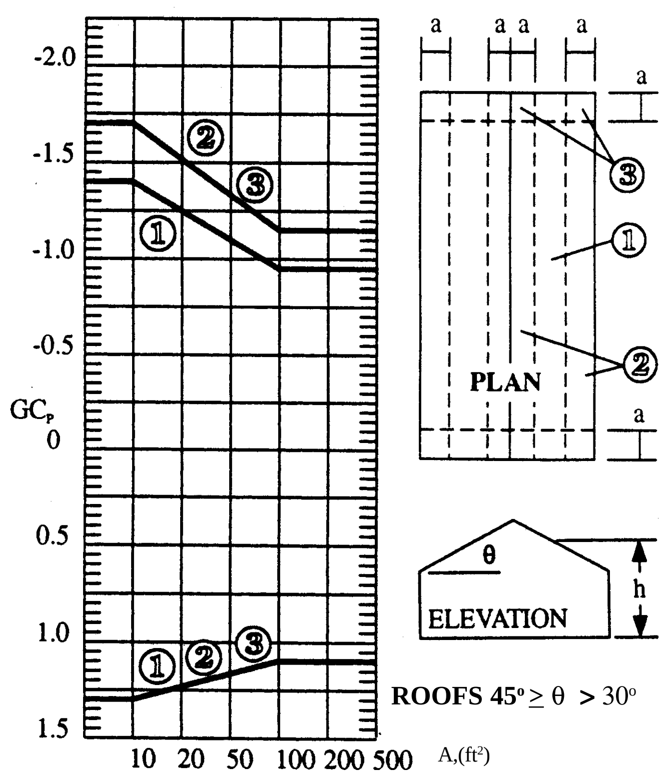
4. a = smaller of 10% of min-imum width and 0.4h, but larger than 4% of minimum width and 3 ft



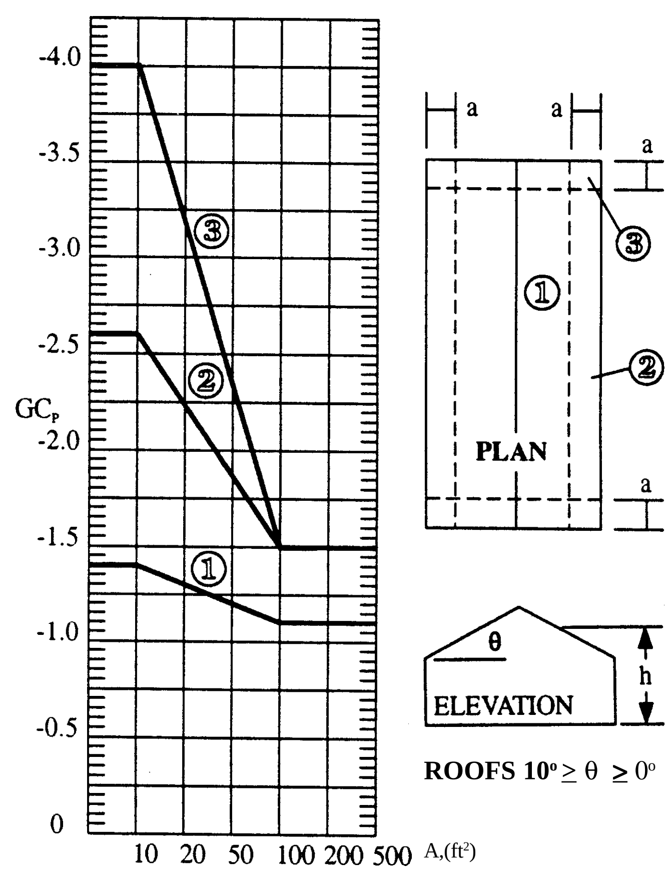
ROOFS 30° ≥ θ > 10°

Table 5.8B

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



ROOFS 45° ≥ θ > 30°



ROOFS 10° ≥ θ ≥ 0°

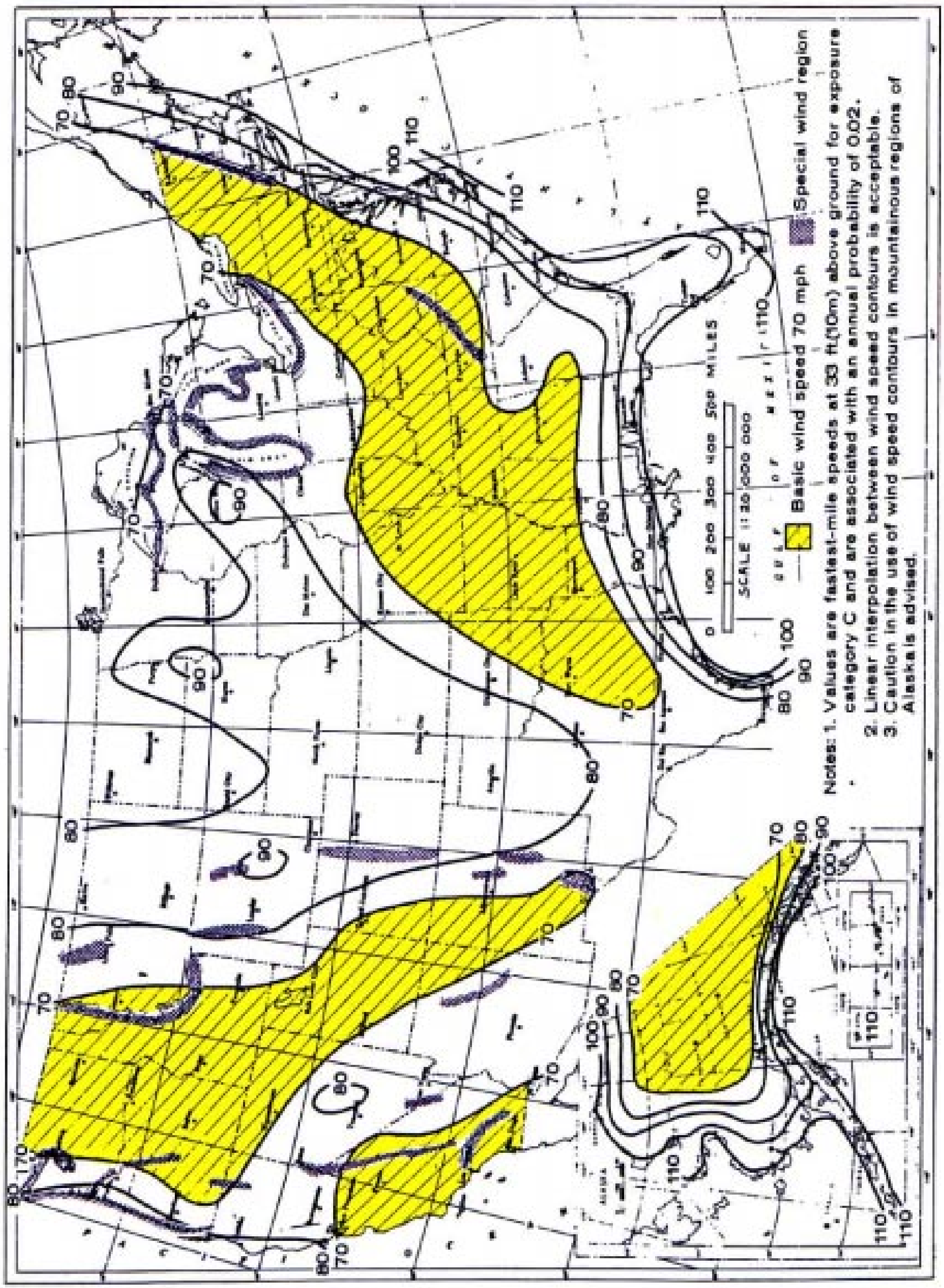


Figure 5.1 Basic Wind Speed (MPH)

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	$0<r<0.2$ $0.2 \le r<0.3$* $0.3 \le r \le 0.6$	-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	$0<r \le 0.6$	1.4r	(-0.7-r)	-0.5

* When the rise to span ratio is (0.2r0.3), 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:

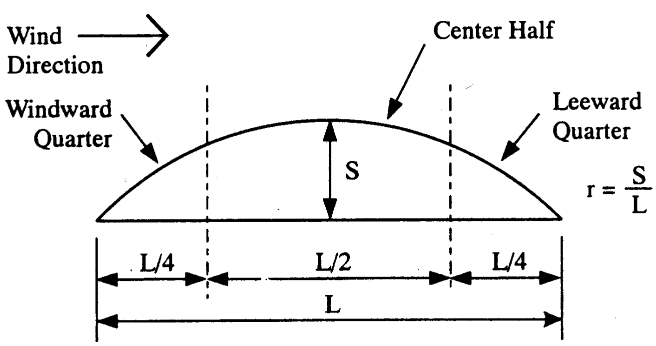


Table 5.8

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	$\pm$0.25