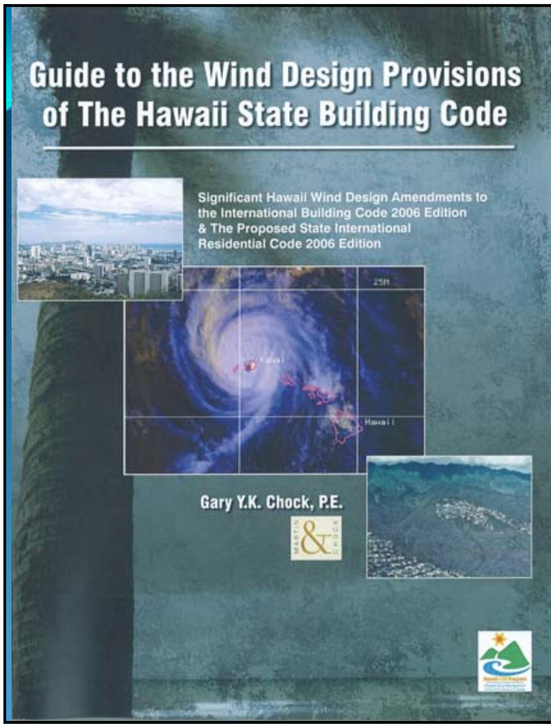


Acknowledgements

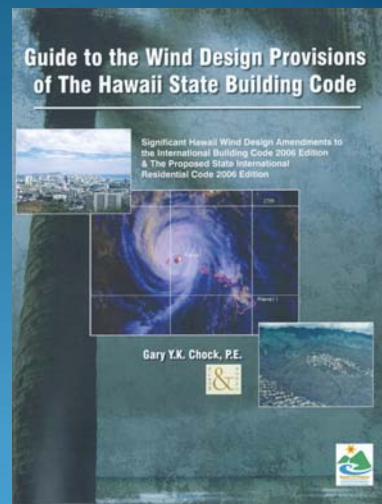
A project of the Hawaii Office of Planning, Coastal Zone Management Program, pursuant to National Oceanic and Atmospheric Administration (NOAA) Award No. NA13NOS4190055, funded in part by the Coastal Zone Management Act of 1972, as amended , administered by the Office of Ocean and Coastal Resource Management, National Ocean Service, NOAA, U.S. Dept. of Commerce. The views expressed herein are those of the author(s) and do not necessarily reflect the views of NOAA or any of its sub-agencies.

AGENDA (time periods not including any questions)

- The State Building Code and its effect on the County Codes (20 min)
- Fundamentals of Wind Design (30 min)
- “Appendix W”: Hawaii Wind Design for Hurricanes and Topographic Effects (30 min)
- “Appendix U”: Hawaii Special Occupancy Requirements for Hurricane Sheltering (30 min)
- Cladding Design for Wind And Windborne Debris (45 min)
- The International Residential Code (20 min)
- Wind Forces on Residential Rooftop PV Panels (20 min)
- Future Changes to the Hawaii Building Code based on catching up to ASCE 7-10 + (30 min)

Speaker / Author

- Gary Chock
- Structural Engineer, Martin & Chock, Inc.
- Author of the Hawaii Wind Design Guide that includes enclosure design standards
- 2010 ASCE Hawaii Chapter Outstanding Civil Engineering Achievement for Windspeed Mapping for the State of Hawaii Incorporating Topographic Effects.
- Structural Engineer on the State Building Code Council
- National ASCE 7 Wind Load Subcommittee
- ASCE Structural Engineering Institute Fellow
- ASCE Fellow
- Diplomate, Coastal Engineer, of the Academy of Coastal, Ocean, Port and Navigation Engineers
- Chair of the ASCE 7 Tsunami Loads and Effects Subcommittee



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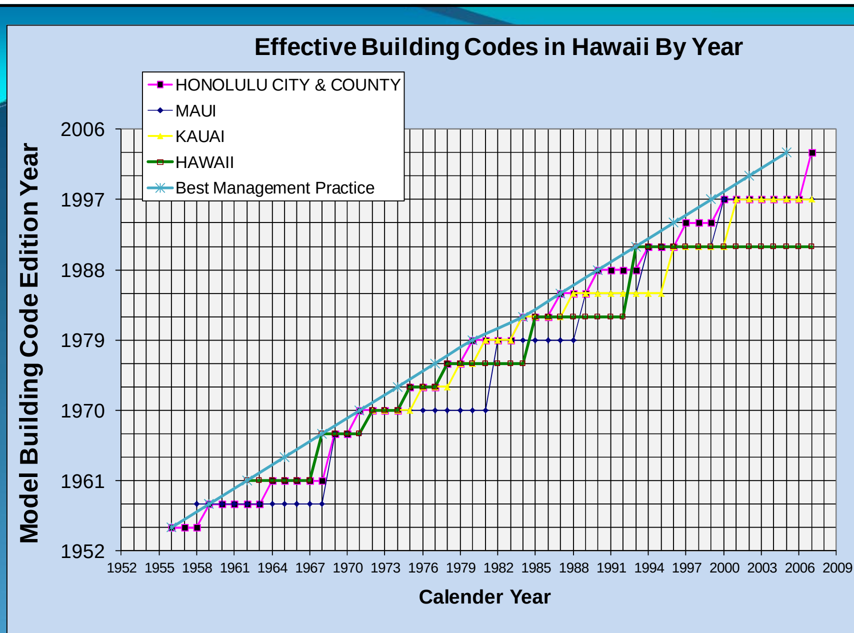
The State Building Code and Design Standards

History and Status



Prior to 2010, the four counties were last in "sync" in 1996, when they adopted the UBC 1991. Before that, they were in "sync" in 1972-1974, when they adopted the UBC 1970.

Examples of county provisions affecting building design and construction that differed by county or were archaic

Edition of the basic model building codes
Omitted model codes
Administration, Fees, and Enforcement
Construction Inspections
Energy Code (sometimes not adopted)
ADA (sometimes not included)
Manufactured Homes
Greenhouses
Indigenous Architecture
Renovations and Code Compliance
Self Certification / Review Waiver
Roofing
Termites and Wood Treatments
High-Rise
Setbacks
Fire Code (State Fire Code not actually adopted)
Flood and Tsunami Regulations (only Honolulu required any hydrodynamic design forces)

Requirements and Standards that were authored or administered by Counties

Code / Standard	Rules or Basis
Building	County authority per HRS 46-1.5 (13)
Fire Code of the County (but need not comply with the State Fire Code)	HRS 132-3,9,16 HAR 12-44, 12-45 State Fire Council creates a model code, but there was no mandate for the counties to use it
Plumbing Code	Uniform Plumbing Code by IAPMO
Electrical	NFPA 70 National Electrical Code
County Energy Efficiency Requirements	Was loosely based on DBEDT Model Energy Code Guidelines; not mandatory
Flood and Tsunami Inundation requirements vary widely by county	No HRS or HAR FEMA minimum
No mechanical code	Only prescriptive fresh air cfm's from Dept. of Health; was not maintained with current knowledge

Requirements and Standards authored or administered by others

State / Federal Agency	Code / Standard	Rules
DLIR	Elevator and Escalators, Dumbwaiters, Rides, and Trains	HAR 12-229 (2000)
DOH	Outside Fresh Air requirements	HAR 11-48 Ventilation
EPA / DOH	Private Sewage Disposal	HAR 11-62 Wastewater Systems
DOH	Toilets, Showers, Lavatories, Food Establishment Sanitation	HAR 11-11, 11-12
DAGS / DCCA Insurance Commissioner	Hurricane Resistive Standards for Shelters and Essential Facilities	Public Hurricane Shelter Criteria (Act 5, 2005) and Act 82 (2007)
DLIR HIOSH	Boilers and Pressure Vessels	HAR 12-8-10, Chapters 220-225
DLIR HIOSH	Window Washing Equipment Supports	HAR 12-8
DOH	Asbestos and Lead Paint Abatement	HAR 11-41, 11-501
Administration Directive for State Buildings	LEED	HRS 196-A

Background: Act 82 (May 21, 2007) State of Hawaii Legislature

- "The adoption of a uniform set of statewide building codes applicable to one and two family dwellings, all other residential uses, and commercial and industrial buildings, and state buildings would make it possible for building owners, designers, contractors, and code enforcers within the State to apply consistent standards. The International Building Code is currently being considered for adoption by all counties. **The health and safety considerations related to the codes are of statewide interest, especially relating to emergency disaster preparedness**."

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HRS Chapter 107, Part II, State Building Code and Design Standards

HRS 107 Part II created the authority of the State Building Code Council, any law to the contrary notwithstanding, to establish a comprehensive State Building Code.

Under HRS §107-25, the State Building Code is required to include various codes and design standards that are listed specifically or generically in the statute. The State Building Code Council includes the State agencies and County jurisdictions with pre-existing regulations affected by a State Building Code.

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State Building Code Council

Attached to DAGS

- Now up to eleven voting members, one non-voting member
- Chairman and Vice Chairman elected annually by members
- Appoints executive director and executive assistant
- Forms technical committees
- Consults with general building contractor associations, and building trade associations
- Adopts state model building codes
- May adopt state code amendments if there is a unanimous consensus of the four county building officials
- May provide education and technical training in the state building code
- Files an annual report to the state legislature

SBCC Code Implementation

- New state building code to be adopted within 18 months of new national/international model building code
- The state building code may include state amendments
- State building design to be in compliance with state building code within one year
- State building design is allowed to be exempt from
  - County codes that have not adopted the state building code
  - County amendments that are inconsistent with the minimum performance objectives of the state building code
  - County amendments that are contrary to amendments adopted by another county

SBCC Code Implementation by the county jurisdiction

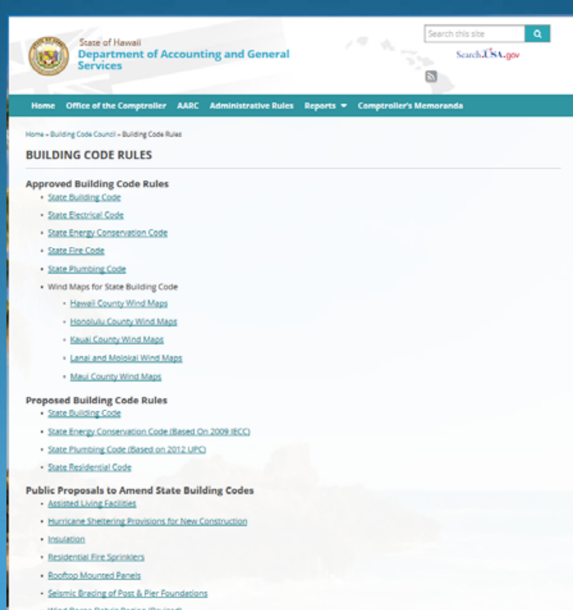
Counties may amend/adopt within two years without seeking approval of the state

- If they do not, the state building code shall become applicable to county as an interim building code until the county amends/adopts state model building code

Counties can create exemptions allowing the exercise of indigenous Hawaiian architecture

The State Building Code, (2006 IBC), became effective April 16, 2010

http://ags.hawaii.gov/bcc/building-code-rules/


State of Hawaii
Department of Accounting and General Services

Home | Office of the Comptroller | AARC | Administrative Rules | Reports | Comptroller's Memoranda

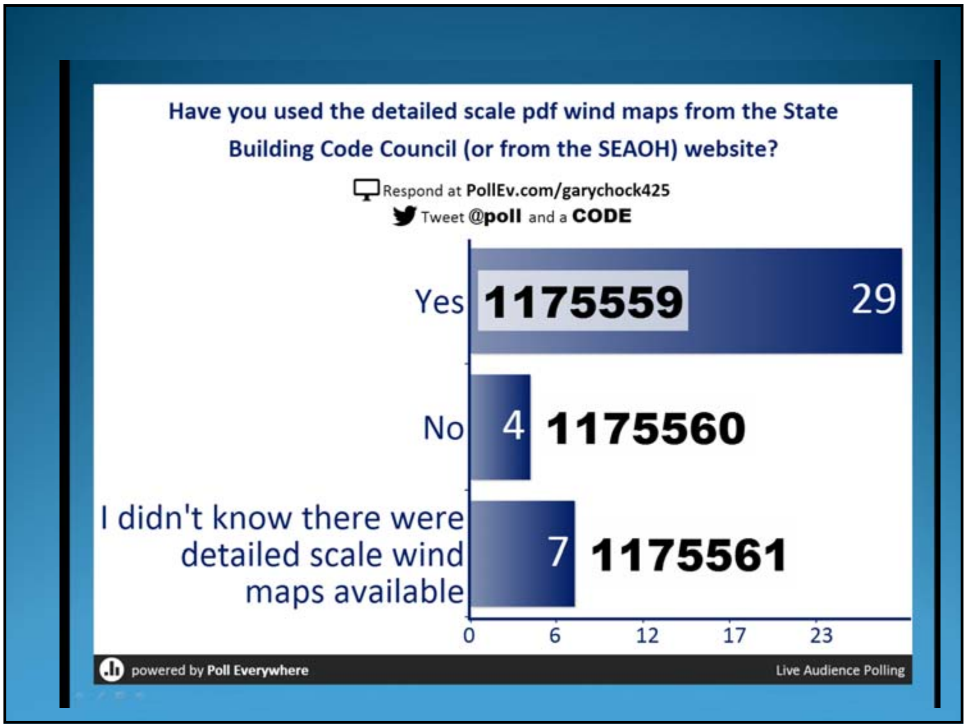
Home » Building Code Council » Building Code Rules

BUILDING CODE RULES

Approved Building Code Rules
- State Building Code
- State Electrical Code
- State Energy Conservation Code
- State Fire Code
- State Plumbing Code
- Wind Maps for State Building Code
  - Hawaii County Wind Maps
  - Honolulu County Wind Maps
  - Kauai County Wind Maps
  - Lanai and Molokai Wind Maps
  - Maui County Wind Maps

Proposed Building Code Rules
- State Building Code
- State Energy Conservation Code (Based On 2009 IECC)
- State Plumbing Code (Based on 2012 UPC)
- State Residential Code

Public Proposals to Amend State Building Codes
- Assisted Living Facilities
- Hurricane Sheltering Provisions for New Construction
- Insulation
- Residential Fire Sprinklers
- Rooftop Mounted Panels
- Seismic Bracing of Post & Pier Foundations
- Wind Borne Debris Region (Revised)



Building Code Status in 2007 prior to the State Building Code

	HONOLULU CITY & COUNTY	MAUI	KAUAI	HAWAII
BUILDING	IBC 2003 with Amendments (effective 9-18-07)	UBC 1997 with Amendments 1986 Housing Code	UBC 1997 with Amendments	UBC 1991 with Amendments
ELECTRIC	NEC 2002	NEC 1999 with Amendments	NEC 1999	NEC 1993
PLUMBING	UPC 1997 with Amendments	UPC 1991 with Amendments	UPC 1997	UPC 1991
MECHANICAL	No Code	No Code	No Code	No Code
FIRE	UFC 1997 with Amendments	Chapter 16.04 Fire Code (UFC 1988 with Amendments) Chapter 132 HRS	UFC 1997 with Amendments	UFC 1988

IBC 2006 Adopted April 16, 2010

- State designs to have complied by April 16, 2011
- County Building Codes to be have been adopted using the Hawaii State Building Code by April 16, 2012
- Honolulu was the only county to miss the deadline; adopted the IBC 2006 in October 2012

Status of Major Codes

Hawaii State Building Code Council	Prepared by Gary Chock				
Required Codes	Status of Major Codes Adopted by the State and the Counties				
CODE	State of Hawaii	Kauai	Honolulu	Maui	Hawaii
Fire	2006 UFC	2006 UFC	2006 UFC	2006 UFC	2006 UFC
Building	2006 IBC	2006 IBC	2006 IBC	2006 IBC	2006 IBC
Plumbing	2006 UPC	2006 UPC	2006 UPC	2006 UPC	2006 UPC
Electrical	2008 NEC	2008 NEC	2008 NEC	2008 NEC	2008 NEC
Energy	2006 IECC	2009 IECC	2006 IECC	2009 IECC	2006 IECC
Residential	None (2006 IRC & 2009 IRC)	2006 IRC	2006 IRC	2006 IRC	Does not apply
Flood (legacy codes)	HRS Chapter 179 Flood (just creates DLNR Board) Chapter 179D Dams (2007)	Chapter 15 Article 1 (amended 6/2006)	2004 LUO Chapter 21.9-10 and ROH Chapter 16.11 (being modified to separate the flood ordinance from the LUO per FEMA)	1993 Chapter 19.62	2011 Chapter 27
Tsunami	none	Essentially none; flood ordinance simply references FEMA flood maps that do not include any tsunami districts mapped. Latest FEMA FIRM maps exclude tsunami (out of scope of the NFIP)	Applicability of legacy 1980 provisions in ROH Chapter 16.11 is unclear, since it just references the FEMA flood maps that do not include any tsunami criteria (out of scope of the NFIP). Also, V zones typically not exceeding the first coastal roadway.	Essentially none; flood ordinance simply references FEMA flood maps that do not include any tsunami criteria mapped; copies Honolulu ordinance. Latest FEMA FIRM maps exclude tsunami (out of scope of the NFIP)	Essentially none; flood ordinance simply references FEMA 2004 flood maps for V zones, that do not actually include tsunami hazard criteria. Latest 2008 FIRM maps exclude tsunami (out of scope of the NFIP)

What About Existing Buildings? IBC Chapter 34 Applies

General: Additions and Alterations to any building or structure shall comply with the requirements of this code for new construction

Hurricane, Wind (and Seismic): If an attached addition or an alteration increases the demand or decreases the capacity of any lateral-load-carrying member by more than 10%, the structural system shall then be made to conform to current code requirements.

Flood: Any addition that constitutes substantial improvement of the existing structure, shall comply with the flood design requirements for new construction, and all aspects of the existing structure shall be brought into compliance with the requirements for new construction for flood design.

(The International Existing Building Code may also be adopted by the county, to allow its use in the repair, alteration, change of occupancy, addition and relocation of existing buildings.)

Which IBC 2006 references does a structural library will need to have ?

- International Building Code 2006
- Hawaii State Amendments, published in 2010 (free download)
- ASCE 7-05
- ASCE 24-05
- ACI 318-05
- ACI 530-05
- AISC 360 (2005 or later) plus AISC 341-05 Seismic
- AISI NAS 2001 + 2004 Supplement
- AF&PA NDS -01
- International Residential Code 2006?
- Wood Frame Construction Manual ANSI/AF&PA WFCM-2001
- AF&PA SDPWS—05 Supplement Special Design Provisions for Wind and Seismic

You probably have most of these already since some are no longer the latest editions; nearly all of these are available from the ICC Catalog

Wind Design Fundamentals

Gary Chock
gchock@martinchock.com

FEMA
CZM Hawaii
Coastal Zone Management

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USA Codes and Standards

- **International Building Code (IBC) adopts by reference the load and safety requirements of American Society of Civil Engineers ASCE 7 Standard, Minimum Design Loads for Buildings and Other Structures**
- Other Standards:
  - Material specific design specifications
  - Non-structural installation standards
  - Testing and qualification standards

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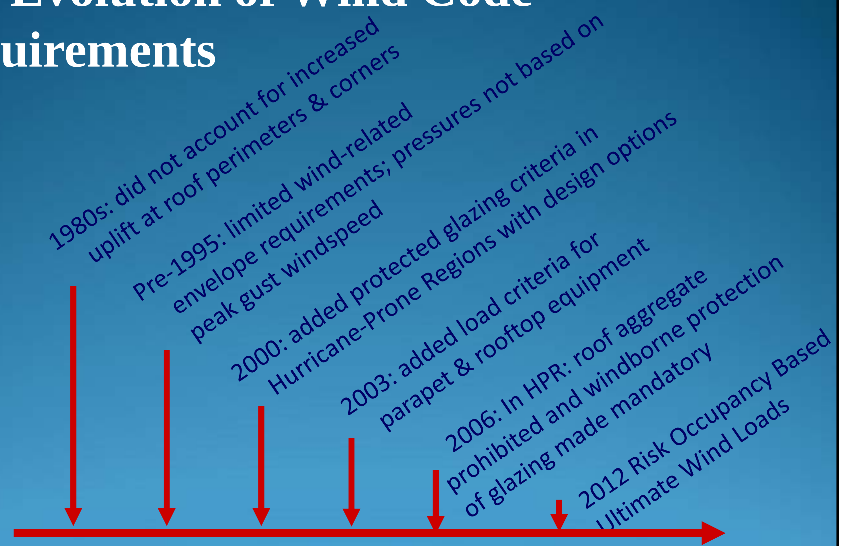
The Evolution of Wind Code Requirements



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Justifiable Differences between Content in the Standard and Local Codes, per ICC, ASCE and NCSEA

"Material that is left in the building code conforms to one of the following criteria:

Relates to local climatic, terrain, or other environmental conditions, which many building officials will wish to specify when adopting the model code by local ordinance. This includes specification of basic wind speeds, terrain, exposure and similar provisions.

Relates to enforcement of types of construction which is often set by condition so local practice, materials availability and construction industry capabilities

Is not presently covered in an adequate manner by a national consensus standard. This includes to material covering roofing materials, hurricane protection of openings, etc."

February, 2005

Jim Rossberg, Structural Engineering Institute of ASCE, representing NCSEA Code Advisory Committee and ASCE/SEI

Wind Resistant Building Code Design Procedure

- Determine the design wind speed & calculate pressures
- Design the Main Wind Force Resisting System
- Design connections to ensure continuous load path
- Provide foundation anchorage resistance
- Calculate wind pressures for the C&C elements
- Design these Components for wind loads and transfer their load to the MWFRS through attachments
- Specify the explicit wind rating requirements for wind-resistive nonstructural products that are elements of the enclosure or attached appurtenances.

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Elements of Wind Resistance

Overall Wind Forces govern

↓

Structural:
The Main Wind Force Resisting System (MWFRS)

The assemblage of structural elements assigned to provide support and stability for the overall structure.

Local Wind Pressures and Windborne Debris govern

↓

Architectural:
Components and Cladding (C&C)

The elements of the building envelope (cladding) and individual elements subject to wind forces (components).

Main Wind Force Resisting System (MWFRS)

- The MWFRS includes all the structural elements working together in an assembled and connected system to transfer the wind forces acting on the structure to the ground.
- MWFRS components include:
  - Roof framing and wall framing
  - Floor and roof diaphragms
  - Shear walls, braces, or frames
  - Foundations

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Components And Cladding

- Includes:
  - Façades
  - Doors & Windows
  - Roofing Components
  - Parapets & Chimneys
  - Ornament & Canopies
  - Attachments (PV panels, signs, antennas, etc.)
  - Rooftop & Ground mounted equipment

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Wind Speeds and Relationship to Pressures

Pressure is a function of ½ x (density of air) x $(\text{wind velocity})^2$

q is a function proportional to $\frac{1}{2}(\rho)(v^2)$

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Wind Velocity relates to Pressure

- Ultimately, the pressure that the wind exerts determines the requirements for the structural system and cladding.
- Pressure is dependent on the following:
  - **Wind Velocity** - quadratically related to pressure. If the wind speed doubles, the pressure will quadruple. Characteristics of the site affect the velocity pressure.
  - **Building Geometry** - the building shape affects pressures on the exterior of the building. These pressures vary by position and height on the building form.

Wind Considerations at a Site

- Detailed wind velocity at a *site* must take into account three additional factors other than the basic wind speed for the *region*:
  - **Terrain Roughness:** accounts for the fact that rougher terrain can slow down wind.
  - **Topographic Effects:** accounts for the fact that wind speed can accelerate where there is a steep rise in terrain.
  - **Directionality**: how likely is it for the topographic effects to occur for each wind direction?

Velocity - Related Pressure q

The Building Code Takes Into account *Site-related* Factors that are Multiplied by the Wind Speed²

q, is the baseline "stagnation" **velocity pressure** for use in subsequent formulae that account for building geometry.

$$q = 0.00256\, K_z K_{zt} K_d V^2$$

Exposure Coefficient K_z classifies the terrain roughness of the area surrounding the site.

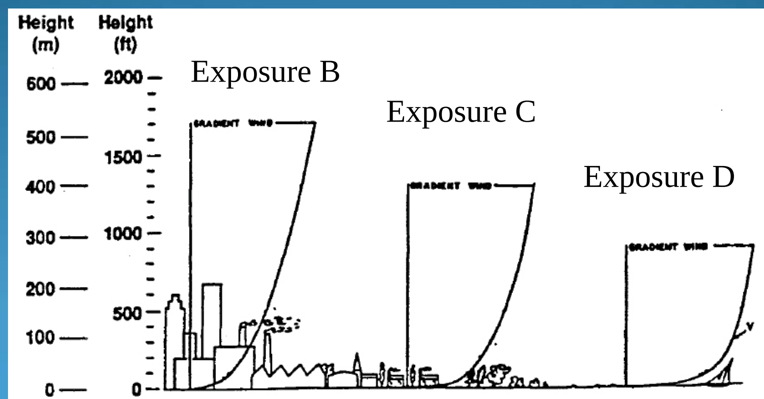
Topographic Effects K_{zt} accounts for the fact that wind speed can accelerate where there are steep rises in terrain.

Wind Directionality K_d accounts for the fact that wind may not align with the weakest axis of a building.

However, this does not account for the geometry of the structure, and that is determined subsequently.

Terrain Roughness

Terrain is grouped into Exposure Categories to account for the terrain roughness effect on the boundary layer.



Holmes, John, 2003. Wind Loading of Structures. Spon Press, New York, NY.

Exposure Category (simplified)

- **Exposure B - Surface Roughness B prevails upwind.** Urban and suburban areas, wooded areas or other terrain with numerous closely spaced obstructions having the size of single-family dwellings or larger.
- **Exposure C assumed if not B or D; Surface Roughness C prevails.** Open terrain with scattered obstructions having heights generally less than 30 feet(9144 mm). This category includes flat open country, and grasslands.
- **Exposure D -Surface Roughness D prevails upwind.** Flat, unobstructed areas and water surfaces. This category includes smooth mud flats, salt flats and unbroken ice.

Exposure Coefficient K_z

- Exposure B shall apply where Surface Roughness B, prevails in the upwind direction for a distance greater than 1,500 ft to 2,600 ft, depending on the building height, or 20 times it height
- Exposure C shall apply for all cases where Exposures B or D do not apply.
- Exposure D shall apply where Surface Roughness D, prevails in the upwind direction for a distance greater than 5,000 ft (1,524 m) or 20 times the building height.

Velocity Pressure Exposure Coefficients, K_h and K_z

Table 27.3-1

Height above ground level, z		Exposure		
ft	(m)	B	C	D
0-15	(0-4.6)	0.57	0.85	1.03
20	(6.1)	0.62	0.90	1.08
25	(7.6)	0.66	0.94	1.12
30	(9.1)	0.70	0.98	1.16
40	(12.2)	0.76	1.04	1.22
50	(15.2)	0.81	1.09	1.27
60	(18)	0.85	1.13	1.31
70	(21.3)	0.89	1.17	1.34
80	(24.4)	0.93	1.21	1.38
90	(27.4)	0.96	1.24	1.40
100	(30.5)	0.99	1.26	1.43
120	(36.6)	1.04	1.31	1.48
140	(42.7)	1.09	1.36	1.52
160	(48.8)	1.13	1.39	1.55
180	(54.9)	1.17	1.43	1.58
200	(61.0)	1.20	1.46	1.61
250	(76.2)	1.28	1.53	1.68
300	(91.4)	1.35	1.59	1.73
350	(106.7)	1.41	1.64	1.78
400	(121.9)	1.47	1.69	1.82
450	(137.2)	1.52	1.73	1.86
500	(152.4)	1.56	1.77	1.89

Notes:

1. The velocity pressure exposure coefficient K_z may be determined from the following formula:
   For 15 ft. $\le z \le z_g$ — $K_z = 2.01\,(z/z_g)^{2/\alpha}$
   For $z < 15$ ft. — $K_z = 2.01\,(15/z_g)^{2/\alpha}$
2. α and z_g are tabulated in Table 26.9.1.
3. Linear interpolation for intermediate values of height z is acceptable.
4. Exposure categories are defined in Section 26.7.

Topographic Effects

Heavier damage is evident at the edge of this cliff compared to otherwise identical buildings.

K_d **Wind Directionality Factor relates the site wind speed to the likelihood of excessive pressure on a structural element of a building.**

Wind directional dependencies can arise from several sources (ASCE and the IBC only account for effect 2):

1. The possibility of statistical directionality of extreme winds, such that the approaching winds may have lower or higher values for some directions.
2. **The possibility that the extreme wind for an event may not coincide with the least favorable orientation of a structural component or system.**
3. The possibility that the surrounding upwind terrain surface roughness conditions are directionally varied.
4. The possibility that topography creates significant speed-up and sheltering effects at a local site and thus creates a *localized* directional dependency of wind speeds.

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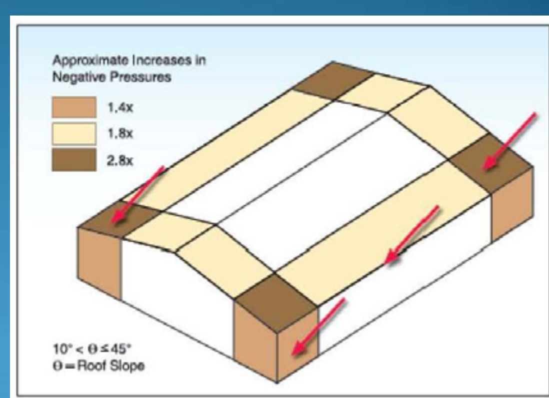
Building Geometry Effects

Shape also determines where there are high local pressures.

Corners are typically the most vulnerable parts of buildings.



Pressures on the Structure

The **Pressure** on the Structure or its Components, p, is a net combination of external and internal pressures:

$$p = \mathbf{q}\, GCp \; - \; \mathbf{q}\, GCp_i$$

- q is the velocity- pressure
- GCp is the gust effect and ***external*** pressure coefficient that varies with structural geometry and location on the structure.
- GCpi is the gust effect and ***internal*** pressure coefficient; the amount of internal pressure will depend on whether the building is enclosed or partially enclosed.

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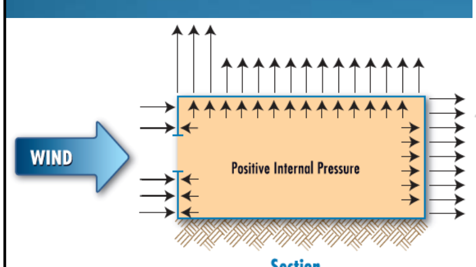
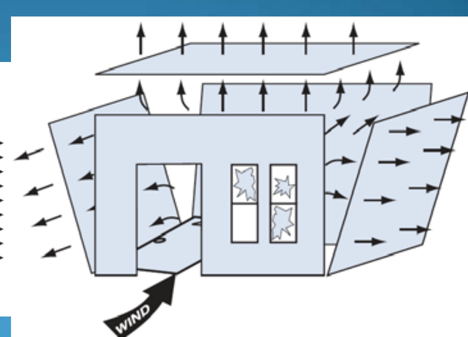
Minimize or Protect Openings to Prevent Indoor Pressure Increase



Design Guide for Improving Critical Facility Safety from Flooding and High Winds: Providing Protection to People and Buildings (FEMA 543 – January 2007).
http://www.fema.gov/library/viewRecord.do?id=2441



Design and Construction Guidance for Community Safe Rooms (FEMA 361 – Second Edition, August 2008).
http://www.fema.gov/library/viewRecord.do?id=1657

Pressure to Forces

F = P x A

Force = Pressure x Area

Wind force is the product of wind pressure and the area of a particular building component or structural member.

To find the force on a given window, door, or entire building, multiply the pressure by the tributary area of the window, door or the exposed projected area of the building.

Wind Forces

- Wind Force is the product of wind pressure by the tributary area of the component or system.
- Wind Forces are calculated separately for:
  - Components and Cladding: Elements of the building envelope; Pressure x effective wind area. The effective wind area of the component accounts for the distribution of peak pressures.
  - Main Windforce Resisting System: The assemblage of structural elements assigned to provide support and stability for the overall structure; Pressure x building surface area.

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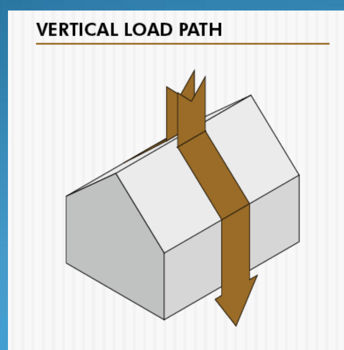
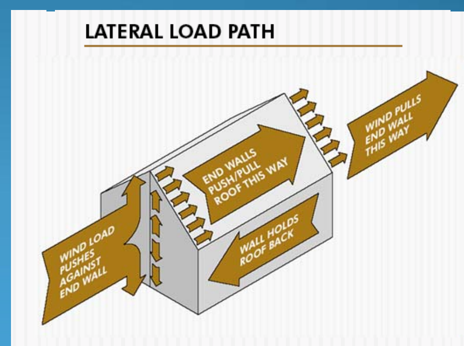
Load Path

The means by which loads acting on a building's surface are transmitted to the foundation.

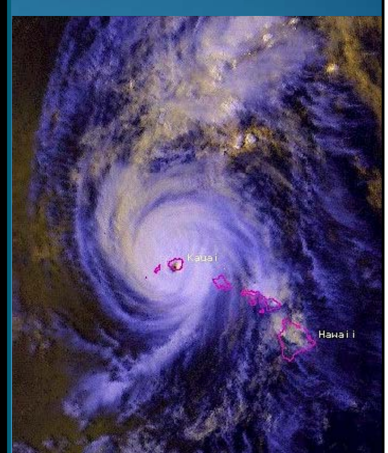




Hawaii is in a hurricane-prone region and a windborne debris region, per the IBC and ASCE -7

HURRICANE-PRONE REGIONS. Areas vulnerable to hurricanes; in the United States and its territories defined as: the U.S. Atlantic Ocean and Gulf of Mexico coasts where the basic wind speed is greater than 90 mph, **and Hawaii**, Puerto Rico, Guam, Virgin Islands, and American Samoa.

WIND-BORNE DEBRIS REGIONS. Areas within hurricane-prone regions located within 1 mile of the coastal mean high water line where the basic wind speed is equal to or greater than 110 mph **and in Hawaii**, or in areas where the basic wind speed is equal to or greater than 120 mph.



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Hurricane Safffir/Simpson Categories are now correlated to the equivalent of wind peak gusts over land

Saffir-Simpson Category	TS	1	2	3	4
Central Pressure mb	993-1007	980-992	965-979	945-964	920-944
1 minute Sustained (NWS) mph	39 - 73	74 - 95	96 - 110	111 - 130	131 - 156
Peak Gust V_{3S} over land (ASCE 7) mph	42 - **80**	81 - **105**	106 - **121**	122 - **143**	144 - **171**

IBC	V_{3S}	85	90	95	100	105	110	120	125	130	135	140	145	150	160	170
UBC	V_{fm}	71	76	80	85	90	95	104	109	114	119	123	128	133	142	152

UBC $V_{fm} = (V_{3S} – 10.5)/1.05$

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Hurricane Categories and Effects in the Pacific

Hurricane Category	Central Pressure Mm of mercury	1-min. Sustained Winds	Peak Gust (over land) mph	Approximate Storm Surge Height (ft.)	Damage Potential (with Tropical Pacific Modifications)
Tropical Depression	≥ 1008	≤ 38 mph (< 17 m/s)	≤ 41	□ 2 ft (□ 0.61m)	Virtually None. Some small dead limbs, ripe coconuts, and dead palm fronds blown from trees. Some fragile and tender green leaves blown from trees such as papaya and fleshy broad leaf plants.
Tropical Storm	99.3-1007	39-73 mph (17-32 m/s)	42-80	2-3 ft (0.61-0.91m)	Some. Minor damage to buildings of light material. Moderate damage to banana trees, papaya trees, and most fleshy crops. Large dead limbs, ripe coconuts, many dead palm fronds, some green leaves, and small branches blown from trees. Albizia trees down.
1	980-992	74-95 mph (33-43 m/s)	81-105	4-5 ft (1.22-1.52m)	Significant. Corrugated metal and plywood stripped from poorly constructed or termite-infested structures and may become airborne. Some damage to wood roofs. Major damage to banana trees, papaya trees, and fleshy crops. Some palm fronds torn from the crowns of most types of palm trees, many ripe coconuts blown from coconut palms. Some damage to poorly constructed signs. Wooden power poles tilt, some rotten power poles break, termite-weakened poles begin to snap. Low-lying coastal roads inundated, minor pier damage, some small craft in exposed anchorage torn from moorings.
2	965-979	96-110 mph (44-49 m/s)	106-121	6-8 ft (1.83-2.44 m)	Moderate. Considerable damage to structures made of light materials. Moderate damage to houses. Exposed banana trees and papaya trees totally destroyed, 10%-20% defoliation of trees and shrubbery. Many palm fronds crimped and bent through the crown of coconut palms and several green fronds ripped from palm trees; some trees blown down. Weakened power poles snap. Considerable damage to piers; marinas flooded. Small craft in unprotected anchorages torn from moorings. Evacuation from some shoreline residences and low-lying areas required.
3	945-964	111-129 mph (30-38 m/s)	122-143	9-12 ft (2.74-3.66 m)	Extensive. Extensive damage to houses and small buildings; weakly constructed and termite-weakened house heavily damaged or destroyed; buildings made of light materials destroyed; extensive damage to wooden structures. Major damage to shrubbery and trees; up to 50% of palm fronds bent or blown off; numerous ripe and many green coconuts blown off coconut palms; crowns blown off of palm trees; up to 10% of coconut palms blown down; 30%-50% defoliation of many trees and shrubs. Large trees blown down. Many wooden power poles broken or blown down; many secondary power lines downed. Air is full of light projectiles and debris; poorly constructed signs blown down. Serious coastal flooding; larger structures near coast damaged by battering waves and floating debris.
4	920-944	130-156 mph (59-69 m/s)	144-171	13-18 ft (296-5.49 m)	Extreme. Extreme structural damage; even well-built structures heavily damaged or destroyed; extensive damage to non-concrete failure of many roof structures, window frames and doors, especially unprotected, non-reinforced ones; well-built wooden and metal structures severely damaged or destroyed. Shrubs and trees 50%-90% defoliated; up to 75% of palm fronds bent, twisted, or blown off. Many crowns stripped from palm trees; numerous green and virtually all ripe coconuts blown from trees; severe damage to sugar cane; large trees blown down; bark stripped from trees; most standing trees are void of all but the largest branches (severely pruned), with remaining branches stubby in appearance; trunks and branches are sandblasted. Most wood poles downed/snapped; secondary and primary power lines downed. Air is full of large projectiles and debris. All signs blown down. Major damage to lower floors of structures due to flooding and battering by waves and floating debris. Major erosion of beaches.
5	< 920	> 157 mph (> 69 m/s)	> 171	> 18 ft (> 5.49 m)	Catastrophic. Building failures; extensive or total destruction to non-concrete residences and industrial buildings; devastating damage to roofs of buildings; total failure of non-concrete reinforced roofs. Severe damage to virtually all wooden poles; all secondary power lines and most primary power lines downed. Small buildings overturned or blown away.

Hawaii Wind Speed (before topographic effects)

- Per IBC 2006 and ASCE 7-05, V = 105 mph 3-second gust
- The Hawaii State and Local County Building Codes require the use of the Hawaii topographic effects
- Engineers utilize the K_{zt} and K_d factor maps for design
- Architects and Specification writers can utlize the more approximate effective velocity V_{eff} maps to specify products

Typical Modes of Hurricane Wind Damage

- Loss of Roofing Components
- Uplift of Decking and Roof Framing Members
- Debris Impacts and Water Damage
- Window & Door Failures
- Wall Failures
- Structural Framing and Wall System Instabilities due to progressive failure of their bracing elements
- Collapse of Pre-Engineered Metal Building and Steel Frames
- Foundation Displacement and Loss of Support and Rollovers of Light Frame Structures and Manufactured Housing
- Storm Surge

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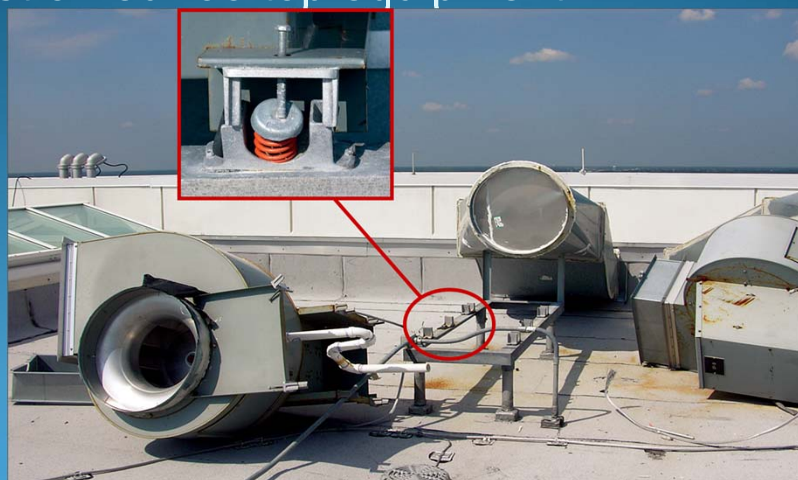
Loss of Roofing and Purlin Framing

Loss of Cladding Components and Windborne Debris Damage to the Enclosure

Lateral displacement of inadequately restrained rooftop equipment



Wind and Debris Related Cladding Damage

Glazing Breakage:
This 75-story high-rise had *95%* of its glass on the lower 40 stories on the east wall broken.

A contibuting cause was glazing damage of the neighboring building and vortexing around the east wall.

Hurricane Ike 2008
Houston, Texas

Large Debris Impact on a School

Uplift of Roofing and Roof Structure

Structural Instability due to loss of bracing

Collapse of Pre-Engineered Steel Frame

Hurricane Charley, FL (FEMA 488)

FEMA 488

CIVIC CENTER / HURRICANE SHELTER
Completed 2002. Designed as a *shelter*, to *basic wind speed* = 140 mph.

Experienced partial wall and roof collapse under estimated max. speed: 125 – 140 mph

There were 1,400 occupants at the time. Prior to collapse there was loss of light metal roofing panels and light gauge steel purlins that were disengaged from steel frame members that spanned up to 200 ft. It was discovered that this was a pre-engineered metal frame building, where overall frame stability relies upon the roofing system and purlin attachments

Example of Storm Surge Damage in V Zone
Galveston After Hurricane Ike (3)

Doran, Kara S.; Plant, Nathaniel G.; Stockdon, Hilary F.; Sallenger, Asbury H.; and Serafin, Katherine A., 2009. Hurricane Ike: Observations and Analysis of Coastal Change. USGS Open-File Report 2009-1061

Displacement off Foundations

End of this module

- Questions?
- (Some will be deferred until the later modules)

Hurricane and Topographic Wind Design Standards for the State of Hawaii Building Code

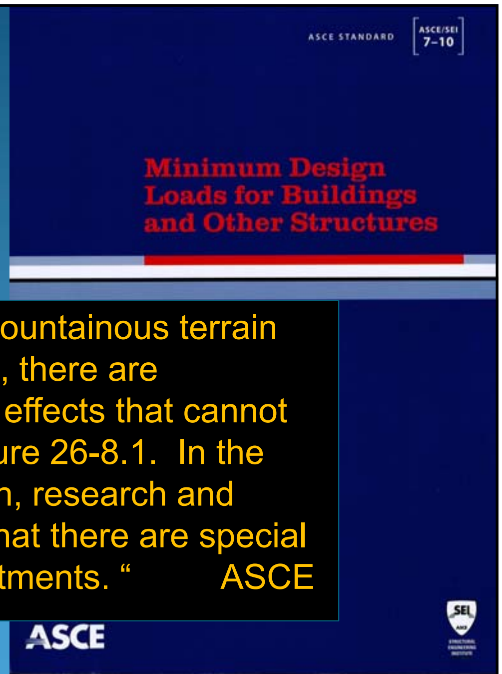
Gary Chock
gchock@martinchock.com

CZM Hawaii
Coastal Zone Management

Reasons for Hawaii Wind Design Provisions

- Terrain-related amplification of wind speeds have been significant factors in losses from past hurricanes impacting Hawaii.
- The International Building Code (IBC) references the ASCE-7 Standard. However, the topography of Hawaii is far more complex than envisioned in the ASCE-7 standard provisions.
  - The ASCE 7 topographic methodology was found to yield incorrect results in a 2001 ARA study commissioned by the Hawaii Hurricane Relief Fund and a 2001 CPP/Martin & Chock study sponsored by the NASA Office of Earth Science.
- The work presented here was awarded the 2010 Outstanding Civil Engineering Achievement by the Hawaii Chapter of ASCE.

Hawaii has been designated as a Special Wind Region where the wind speeds are governed by the microzonation maps adopted in the Hawaii State Building Code



"Due to the complexity of mountainous terrain and valley gorges in Hawaii, there are topographic wind speed-up effects that cannot be addressed solely by Figure 26-8.1. In the Hawaii Special Wind Region, research and analysis have established that there are special K_{zt} topographic effect adjustments. " ASCE

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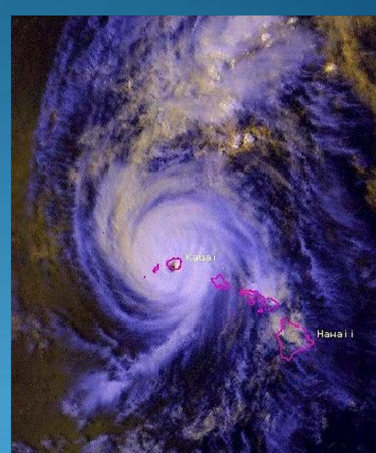
Basic Goals Achieved by the Hawaii State Building Code Hurricane Resistive Provisions

- Uniform-risk wind speed including topographic effects mapping for reference in the local building code based on probabilistic and reliability methods.
- Achieve a nearly uniform level of protection for hurricane resistant structural design throughout the Hawaii.



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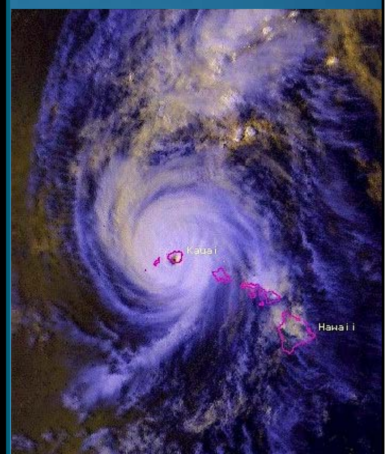
Hawaii is in a hurricane-prone region and a windborne debris region, per the IBC and ASCE -7

HURRICANE-PRONE REGIONS. Areas vulnerable to hurricanes; in the United States and its territories defined as: the U.S. Atlantic Ocean and Gulf of Mexico coasts where the basic wind speed is greater than 90 mph, **and Hawaii**, Puerto Rico, Guam, Virgin Islands, and American Samoa.

WIND-BORNE DEBRIS REGIONS. Areas within hurricane-prone regions located within 1 mile of the coastal mean high water line where the basic wind speed is equal to or greater than 110 mph **and in Hawaii**, or in areas where the basic wind speed is equal to or greater than 120 mph.



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Monte Carlo simulation of the East-Central Pacific region Contours show number of times in 10 years a storm (of at least tropical storm intensity) passes within 75 Nmi of a site

30-yr. Historical Tendency

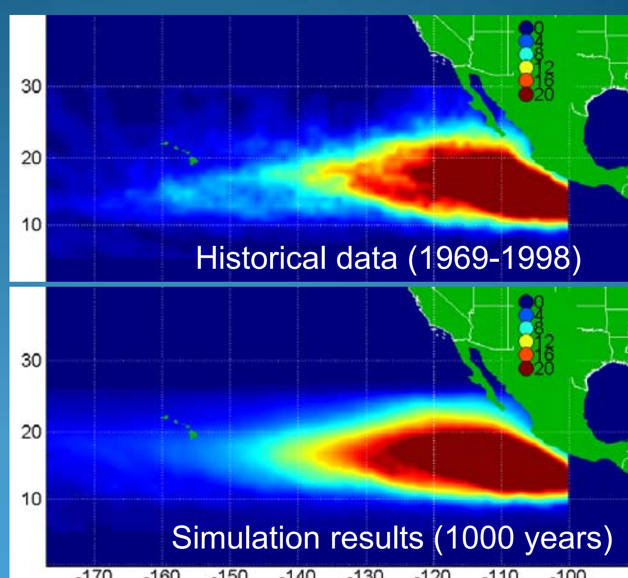
West of 140°W, most storms go south of Hawaii, some drift north but die off in intensity, some make a sharp turn north while retaining stronger intensity

Monte Carlo Simulation

Simulated storm origins (year, month, initial direction) per historical tendency

Track each storm across the Pacific using formulas for direction, translation speed, and intensity

Storms "die" in simulation when intensity is low enough



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International Building Code 2006 Hawaii Structural Amendments

- Appendix U Hawaii Hurricane Sheltering Provisions for New Construction
- Appendix W Hawaii Wind Design Provisions for New Construction

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Topographic Effects for Hawaii Special Wind Region

1609.3 Basic Wind Speed and Topographic and Directionality Factors. The basic wind speed, in mph, for the determination of the wind loads shall be determined by Figure 1609. ***Special wind regions near mountainous terrain and valleys are accounted within the Topographic Factor defined in Section 1609.3.3.*** Wind speeds derived from simulation techniques shall only be used in lieu of the basic wind speeds given Figure 1609 when, (1) approved simulation or extreme-value statistical-analysis procedures are used (the use of regional wind speed data obtained from anemometers is not permitted to define the hurricane wind speed risk in Hawaii) and (2) the design wind speeds resulting from the study shall not be less than the resulting 700-year return period wind speed divided by √1.6.

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Development of Topographic Wind Speed-up Methods for Hawaii

- From 2000 to 2002, the NASA Office of Earth Science sponsored two projects under principal investigators Gary Chock and Jon Peterka that produced new methodologies pertaining to hurricane wind speeds and topographic effects.
- Subsequent development for building code application were sponsored by FEMA, NOAA, and the State of Hawaii.
- To determine speedup factors for Oahu and Kauai, terrain models of portions of the island terrain were constructed and tested in the wind tunnel. Wind speedups or reductions were measured at several hundred locations. Martin & Chock then constructed a phenomenological model to fit the measured data, and used that model to predict the wind speedup in all areas of Oahu, Kauai, Lanai, and Molokai.
- For the islands of Hawaii and Maui, Computational Fluid Dynamics are used via a Mesoscale Model.

IBC 2006 Amendments

- Appendix W – Hawaii Wind Design Provisions for New Construction
  - **1609.1.1 Determination of wind loads.** Wind loads on every building or structure shall be determined in accordance with Chapter 6 of ASCE 7. Minimum values for Directionality Factor, K_d, Velocity Pressure Exposure Coefficient, K_z, and Topographic Factor, K_{zt}, shall be determined in accordance with Section 1609.
    - Determination of Wind Loads via maps of
      - Topographic effects
      - Terrain Exposure
  - Effective wind speed maps for simplified specification of high wind components and cladding

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Special wind regions near mountainous terrain and valleys are accounted within the Topographic Factor , Directionality Factor, and Effective Wind Speeds that are defined within the Hawaii Building Code in

Appendix W – Hawaii Wind Design Provisions for New Construction

- **Topographic Factor maps** giving the maximum topographic effect due to mountainous topography
- Tables of **Directionality Factor** that take into account site directional probabilities of the occurrence of maximum effects
- **Exposure maps** giving the definition of the boundary layer as influenced by terrain
- **Effective Wind Speed** for Cladding and Components based on wind speeds adjusted for mountainous topography

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Formulation of the Hawaii Code Amendments Developed for Use within ASCE 7

$$q = 0.00256\, K_z K_{zt} K_d V^2 I$$

- **Design Basic Windspeed 3-sec. gust, V,** was derived utilizing a Monte Carlo simulation of the East-Central Pacific region.
- **Mapping incorporating Topographic Effects** for structural design specification of speed-up factors, K_{zt} is defined by maps.
- **Wind Directionality Factor, K_d**, weighting of the probability of critical wind directional variation is defined in look-up tables.
- **Exposure Category** Determination for K_z, classification to account for terrain roughness/land use and topographic factors is defined in maps.
- **Effective Wind Speed, V_{eff}**, for use with prescriptive and simplified design provisions, implicitly incorporating K_{zt} and K_d, is defined in maps.

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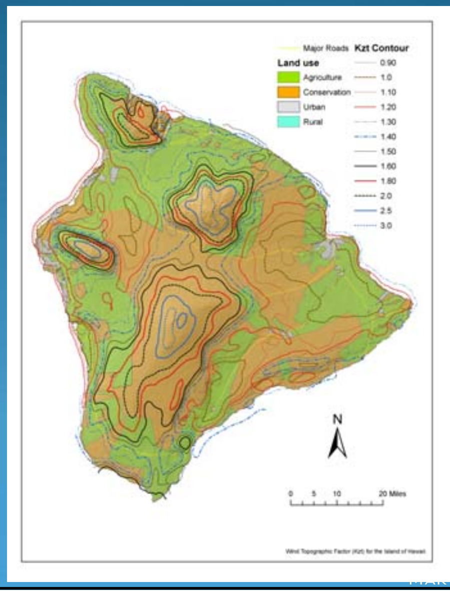
Maximum Topographic Factor - Hawaii

$q = 0.00256\, K_z\, \mathbf{K_{zt}}\, K_d\, V^2\, I$



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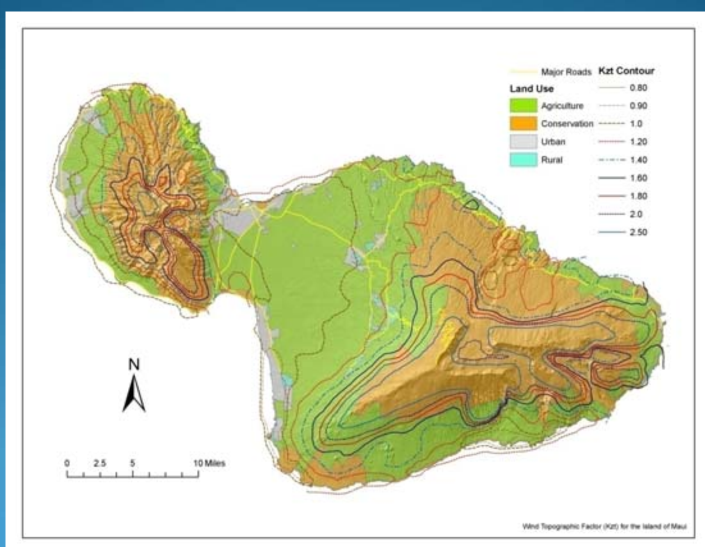
Maximum Topographic Factor - Maui

$q = 0.00256\, K_z\, \mathbf{K_{zt}}\, K_d\, V^2\, I$



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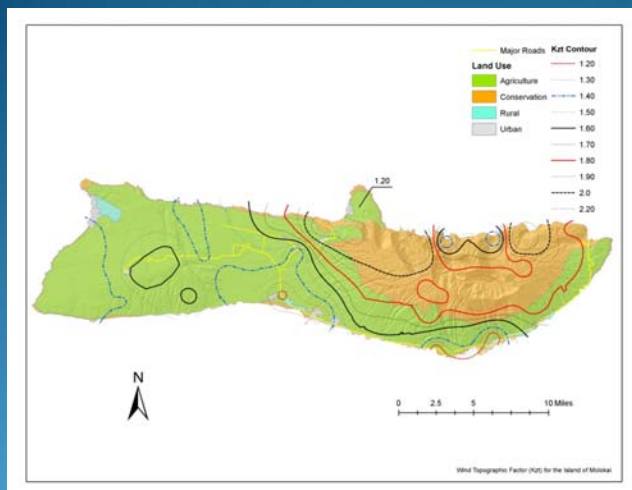
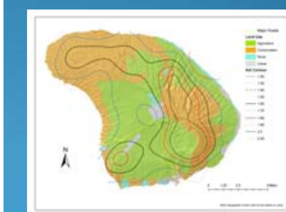
Maximum Topographic Factor – Molokai and Lanai

$q = 0.00256\, K_z\, \mathbf{K_{zt}}\, K_d\, V^2\, I$





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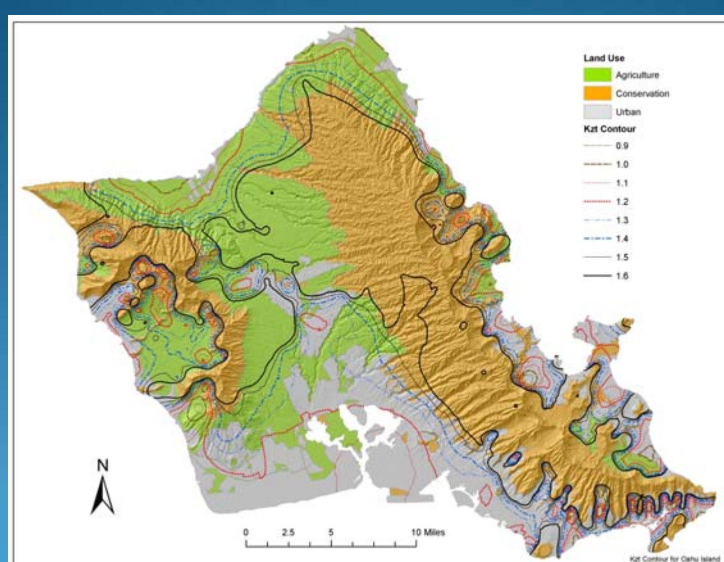
1609.3.3 Topographic Effects. Wind speed-up effects caused by topography shall be included in the calculation of wind loads by using the factor Kzt, where Kzt is given in Figure 1609.3.3.

$q = 0.00256\, K_z\, \mathbf{K_{zt}}\, K_d\, V^2\, I$



Special wind regions near mountainous terrain and valleys are accounted within the Topographic Factor defined in Section 1609.3.3

Figure 1609.3.3 Peak Topographic Factor Kzt for Building Heights up to 100 feet

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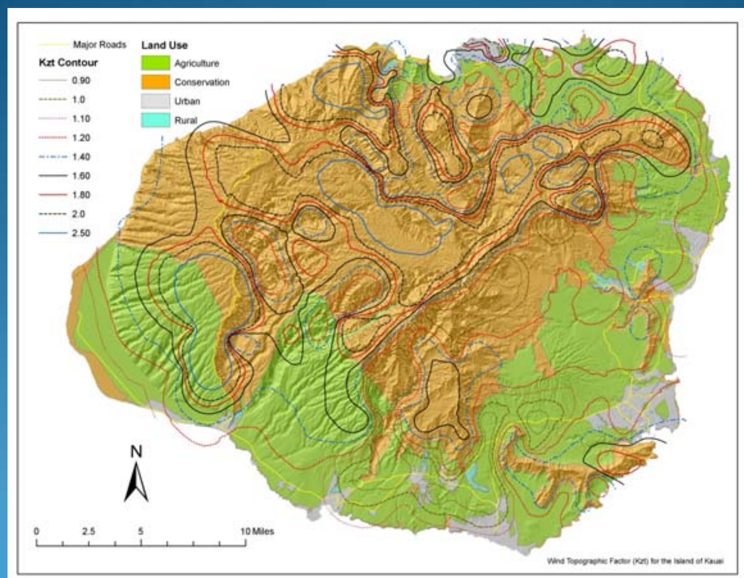
Maximum Topographic Factor - Kauai

$q = 0.00256\, K_z\, \boldsymbol{K_{zt}}\, K_d\, V^2\, I$



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K_d Wind Directionality Factor relates the site wind speed to the likelihood of excessive pressure on a structural element of a building. Probabilistically weighted Kd are calculated to provide a level of safety consistent with wind load exceedance probabilities inherent in flat land open terrain sites in hurricane-prone areas.

Wind directional dependencies can arise from several sources:

1. The possibility of statistical directionality of extreme winds, such that the approaching winds may have lower or higher values for some directions.
2. The possibility that the extreme wind for an event may not coincide with the least favorable orientation of a structural component or system.
3. The possibility that the surrounding upwind terrain surface roughness conditions are directionally varied.
4. The possibility that topography creates significant speed-up and sheltering effects at a local site and thus creates a *localized* directional dependency of wind speeds.

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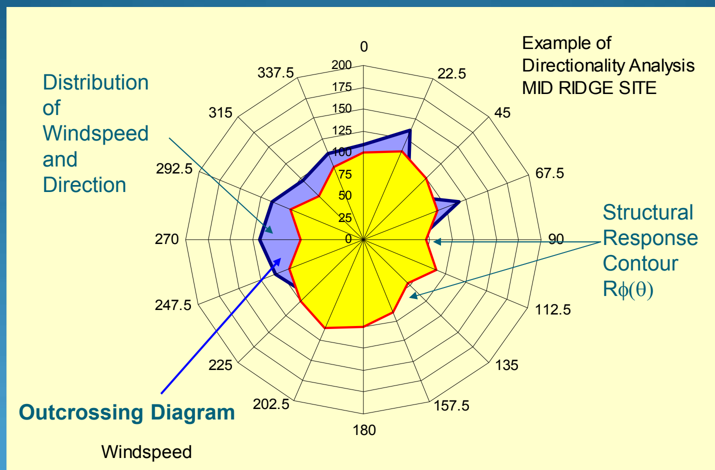
The Directionality Factor K_d accounts for the probability that the wind direction may not be oriented with the weakest axis of the building, considering directional variation in *both* the response *and* wind speed functions



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Determination of the Hawaii Directionality Factors, **K_d**, accounts for all significant sources of directional winds

- The ASCE-7 standard includes a directionality factor, K_d, but it is currently based on flat terrain conditions without orographic channeling and topographic amplification.

The procedure for the Hawaii Building Code will utilize a customized K_d wind directionality factor, which accounts for

- Effect 2, that the probability that the maximum wind may not impact the structural component or system in its weakest orientation,
- Effect 4, that the local wind speeds for the design return period have directional dependence at a site.

Detailed calculations have been performed so that the designer will not have to derive these effects.

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Response Functions:

- A response function is the aerodynamic response boundary that defines the wind speed required for a given azimuth to produce a limiting structural capacity in a system or component.
- In general, the response function shape V_R is related to the directional pressure coefficient, $C_p(\theta)$, or force coefficient, $C_f(\theta)$ as:

  $V_R(\theta) = f(\sqrt{C_p(\theta)})^{-1}$

- This takes in account that the wind load on any structural system or component varies with wind direction.

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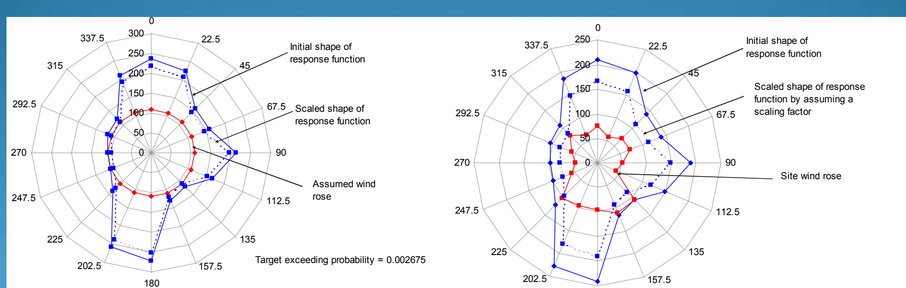
Outline of the Procedure Described in the Book

- Determine the hurricane wind outcrossing exceedance probability of the selected response function for a flat land control site.
- Iteratively determine the value of K_d necessary for the selected response function to have a wind hazard exceedance probability equal to the control site. Consider all (16) possible orientations of the structure.
- Repeat the calculation for the next response function.
- Repeat the procedure for all sites.



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1609.3.4 Directionality Factor. The wind directionality factor, Kd, shall be determined from Tables 1609.3.4 (a) and 1609.3.4 (b).

Table 1609.3.4(a) Kd Values for Main Wind Force Resisting Systems - Buildings Sited on Oahu, Hawaii 1, 2

Topographic Location on Oahu, Hawaii	Main Wind Force Resisting Systems		Main Wind Force Resisting Systems with totally independent systems in each orthogonal direction		Biaxially Symmetric and Axisymmetric Structures of any Height and Arched Roof Structures
	Mean Roof Height less than or equal to 100 ft.	Mean Roof Height greater than 100 ft.	Mean Roof Height less than or equal to 100 ft.	Mean Roof Height greater than 100 ft.	
Sites within valleys at an elevation of at least 50 ft. but not greater than 500 ft.	0.65	0.70	0.70	0.75	0.85
Central Oahu above an elevation of 500 ft, the Ewa and Kapolei plains, and coastal areas with Kzt (10m) no greater than 1.2	0.75	0.80	0.75	0.80	0.95
All other areas, including Hills, Hillsides, Ridges, Bluffs, and Escarpments at any elevation or height; coastal and inland areas with Kzt (10m) greater than 1.2	0.70	0.75	0.75	0.80	0.90

Notes:
1. The values of K_d for other non-building structures indicated in ASCE-7 Table 6-4 shall be permitted.
2. Site-specific probabilistic analysis of K_d based on wind-tunnel testing of topography and peak gust velocity profile shall be permitted to be submitted for approval by the Building Official, but K_d shall have a value not less than 0.65.

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Table 1609.3.4(b) Kd Values for Components and Cladding of Buildings Sited on Oahu, Hawaii [1, 2]

Topographic Location on Oahu	Components and Cladding		
	Mean Roof Height less than or equal to 100 ft.	Mean Roof Height greater than 100 ft.	Occupancy Category IV Buildings and Structures
Sites within valleys at an elevation of at least 50 ft. but not greater than 500 ft.	0.65	0.70	0.75
Central Oahu above an elevation of 500 ft, the Ewa and Kapolei plains, and coastal areas with Kzt (10m) no greater than 1.2	0.75	0.80	0.85
All other areas, including Hills, Hillsides, Ridges, Bluffs, and Escarpments at any elevation or height; coastal and inland areas with Kzt (10m) greater than 1.2	0.70	0.75	0.80

Notes:
1. The values of Kd for other non-building structures indicated in ASCE-7 Table 6-4 shall be permitted.
2. Site-specific probabilistic analysis of Kd based on wind-tunnel testing of topography and peak gust velocity profile may be submitted for approval by the Building Official, but in any case subject to a minimum value of 0.65.

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The Relationship between the Maps of K_{zt} and Tables of K_d

- Use of a single map for design representing the *maximum Kzt* value (of topographic speed-up squared) from *any* direction would be the simplest to apply but overly conservative.
- ASCE provides a basis for making an adjustment of wind load by means of the directionality factor K_d, taking into account the probability that the predominant extreme wind speed-up may not align with the least favorable orientation of a structural component or system
- For the Hawaii Building Code a probabilistic adjustment factor K_d is used in a methodology utilizing a single *non-directional* map of K_t, expressed at 10m , and then accounting for the *directional* probabilities of wind through specification of K_d based on probabilistic calculations of individual site wind rose data.
- The Hawaii State Building Code has values for K_d for each island and terrain regimes

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Effective Wind Speed Maps for Components and Cladding

In areas of topographic speed-up, this new velocity term is defined in order to provide a nearly uniform level of protection for hurricane hazard, regardless of whether the designer uses the IBC, Simplified ASCE, or the International Residential Code (IRC), WFCM, etc.

Algebraically-normalized maps of "$V_{effective}$", i.e.,
V multiplied by $\sqrt{(K_{ztopograhic} \times K_{directional} / 0.85)}$
allow implicit consideration of topographic effects for Cladding and Component design.

The $V_{effective}$ values can be used for performance-specified building components and cladding, as well as when using prescriptive design tables and existing reference standards and simplified methods based on wind speed tables.

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1609.3.2 Effective basic wind speed conversion.

For the Simplified Wind Load Method of Section 1609.6, Wind uplift connectors of Section 2308.10.1, the provisions of ASCE Section 6.4, and the AF & PA Wood Frame Construction Manual for One- and Two-Family Dwellings, the basic wind speed value used for determination of the wind loads, shall be the Effective Basic Wind Speed, Veff , determined by Figure 1609.1.1.1, which adjusts the basic wind speed for special topographic wind regions of Oahu.

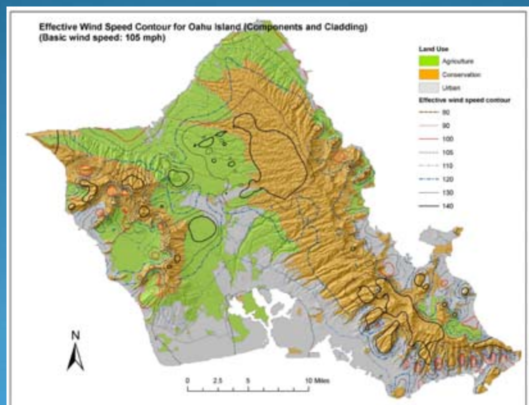

Figure 1609.1.1.1 Effective Basic Wind Speed, V_{eff}, for Components and Cladding for Buildings less than 60 feet tall.

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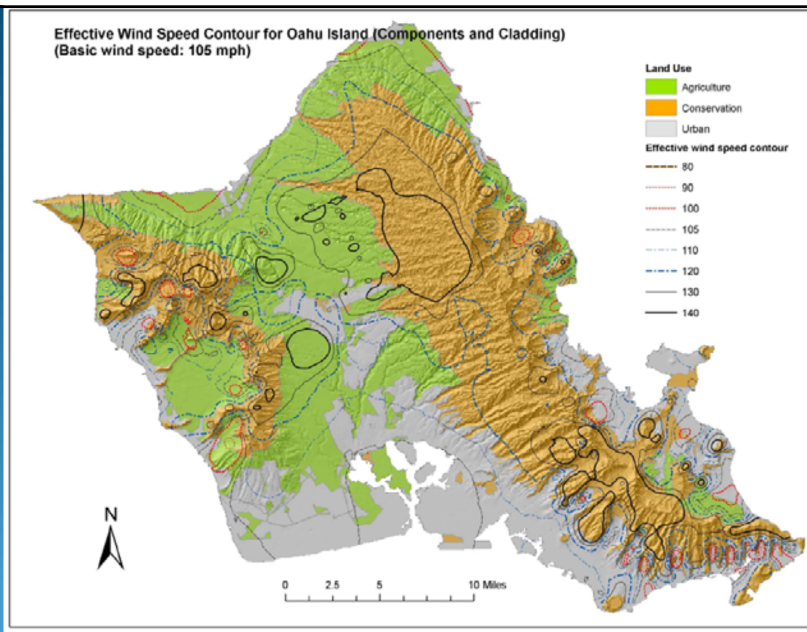

Figure 1609.1.1.1 Effective Basic Wind Speed, V_{eff}, for Components and Cladding for Buildings less than 60 feet tall.

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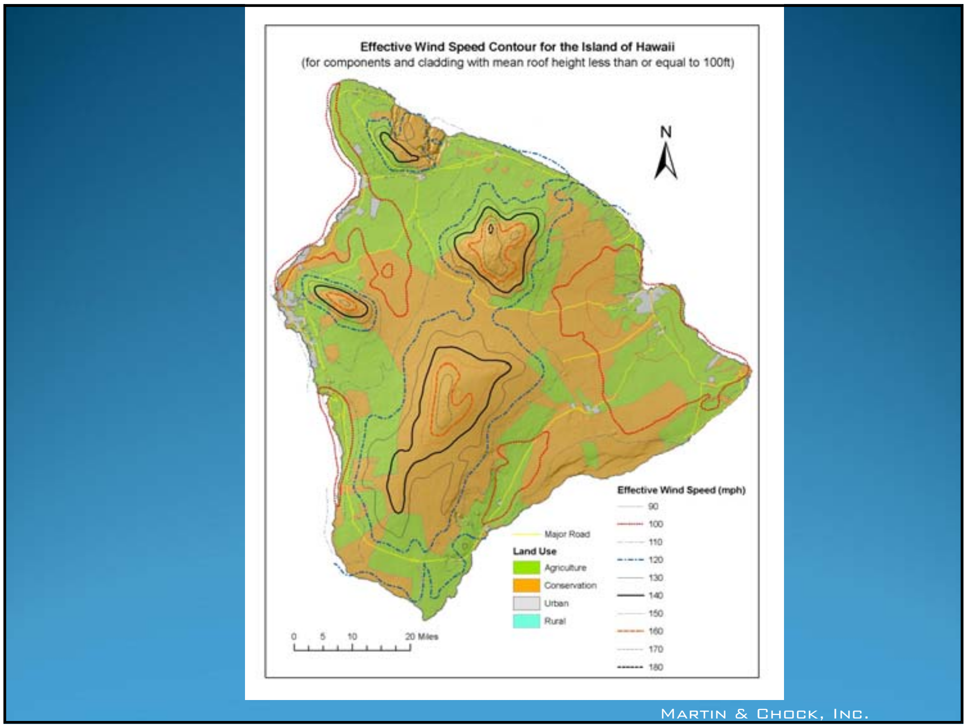
Effective Wind Speed Contour for the Island of Hawaii
(for components and cladding with mean roof height less than or equal to 100ft)
N
Effective Wind Speed (mph)
90
100
110
120
130
140
150
160
170
180
Major Road
Land Use
Agriculture
Conservation
Urban
Rural
0 5 10 20 Miles
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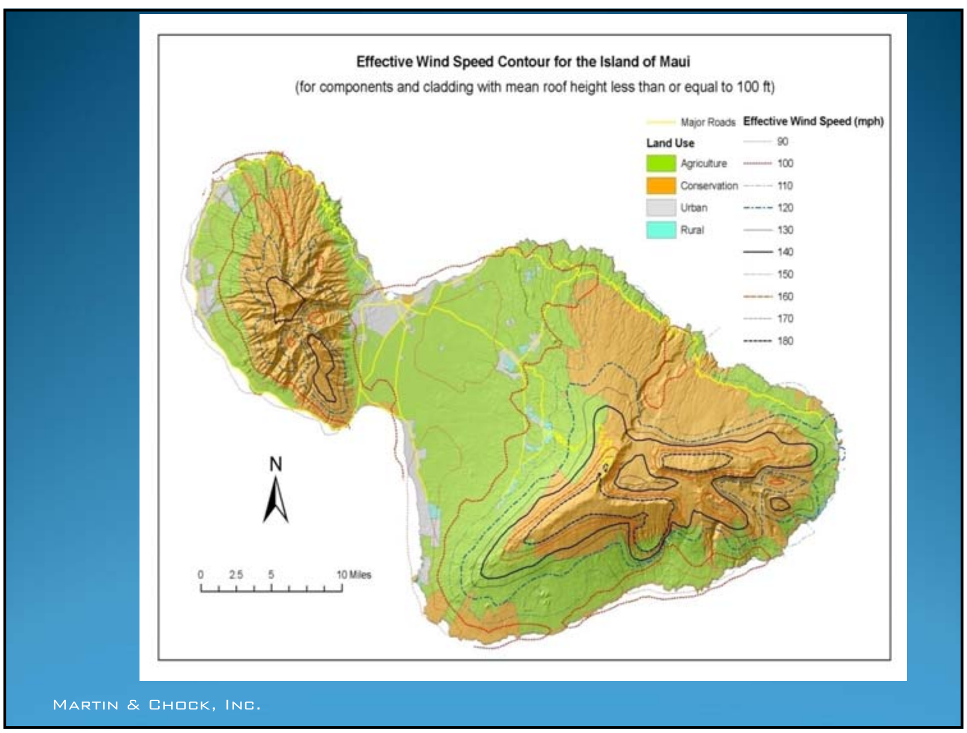
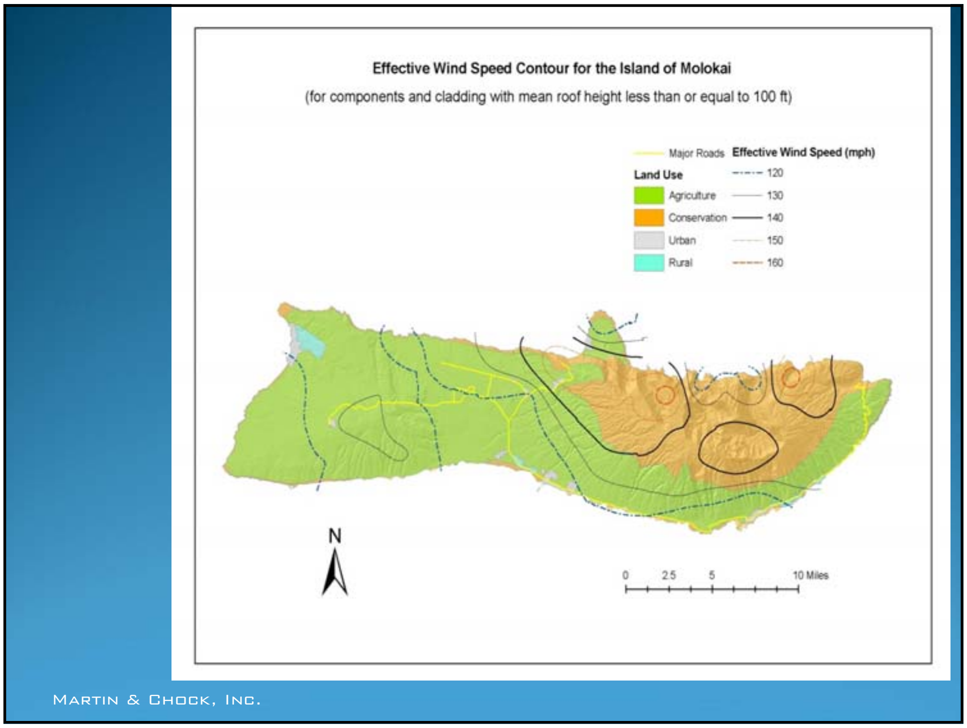

Effective Wind Speed Contour for the Island of Maui
(for components and cladding with mean roof height less than or equal to 100 ft)
Major Roads
Effective Wind Speed (mph)
Land Use
Agriculture
Conservation
Urban
Rural
90
100
110
120
130
140
150
160
170
180
N
0 2.5 5 10 Miles
Martin & Chock, Inc.



Effective Wind Speed Contour for the Island of Molokai
(for components and cladding with mean roof height less than or equal to 100 ft)
Major Roads
Effective Wind Speed (mph)
Land Use
Agriculture
Conservation
Urban
Rural
120
130
140
150
160
N
0 2.5 5 10 Miles
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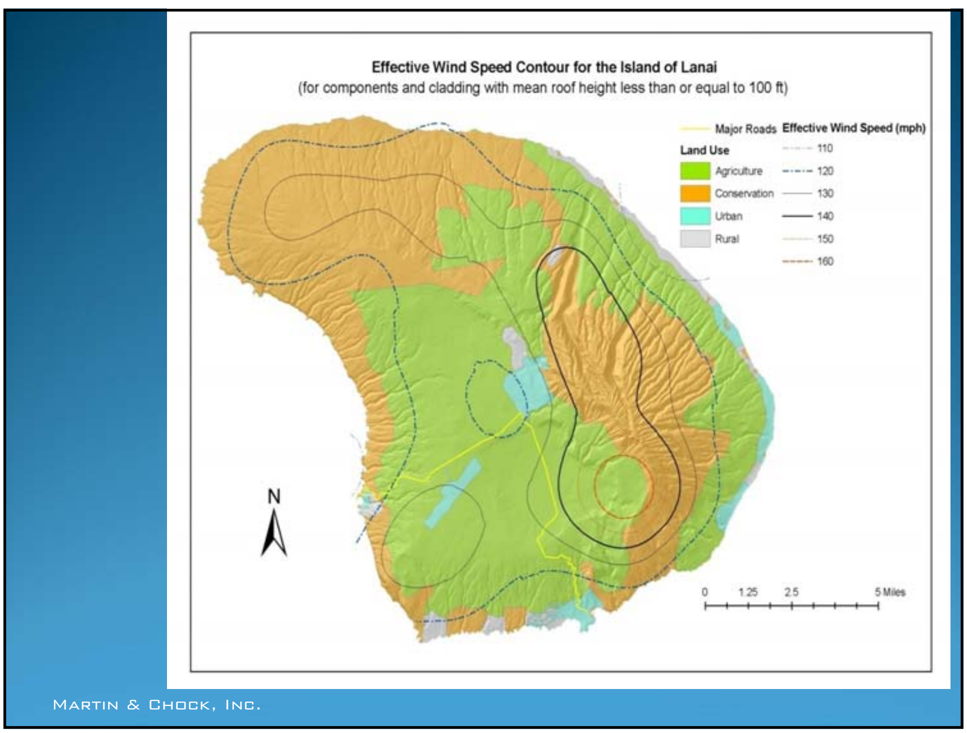

Effective Wind Speed Contour for the Island of Lanai
(for components and cladding with mean roof height less than or equal to 100 ft)
Major Roads
Effective Wind Speed (mph)
Land Use
Agriculture
Conservation
Urban
Rural
110
120
130
140
150
160
N
0 1.25 2.5 5 Miles
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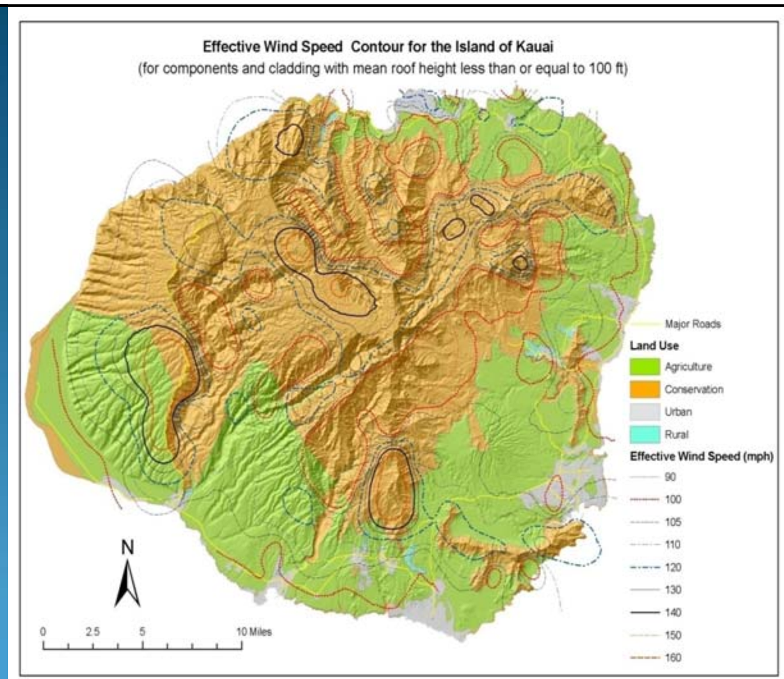

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Lanai and Molokai

- Lanai has the geometry like a single mesoscale smooth mountain directly over the water, so the top of the island has high effective windspeeds.
- Molokai has severe coastal escarpments on the north that causes immediate topographic amplification of windspeeds off the ocean.

Exposure Category Mapping

- Data source layers inserted into a GIS map model include:
  - The NOAA land cover produced for of the National Land Cover Database
  - Landsat imagery
  - Statistically fitted gust profile power law coefficients determined at representative sites by wind-tunnel measurement of mean and gust velocity profiles
- Then the map was reclassified into Exposure Categories interpreting these layers for the terrain criteria

National Land Cover Database

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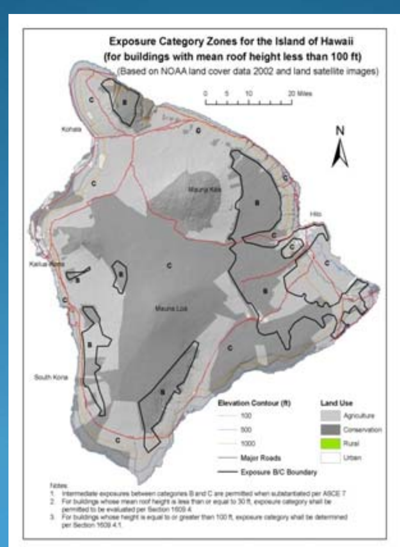
Exposure Category - Hawaii



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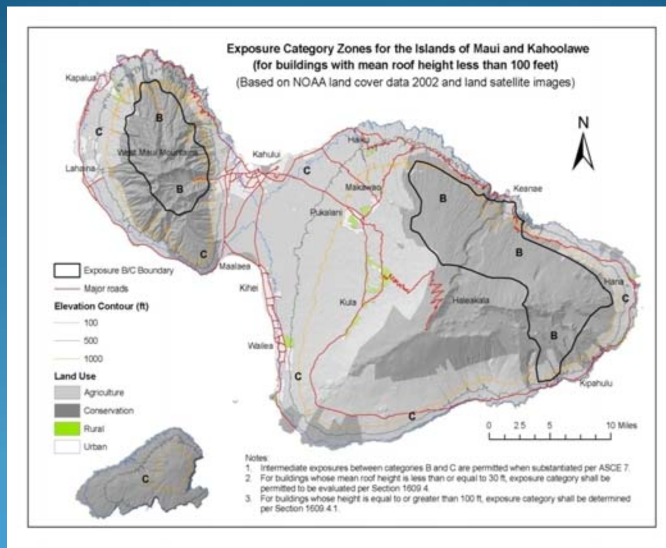
Exposure Category - Maui



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Exposure Category - Molokai and Lanai

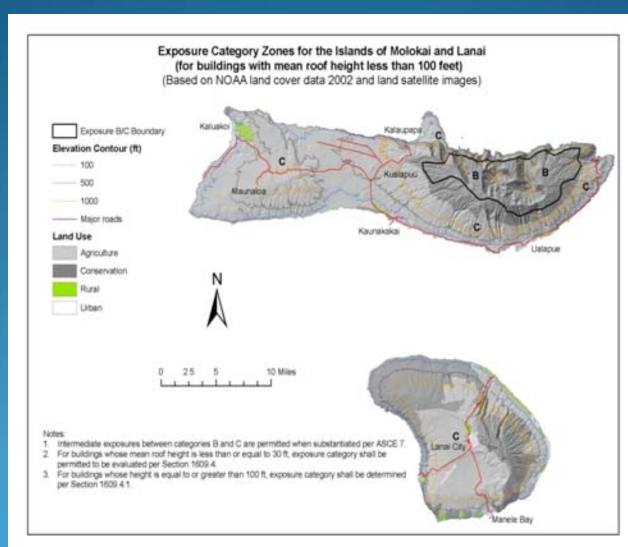

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Figure 1609.4 Exposure Category Zones for Oahu

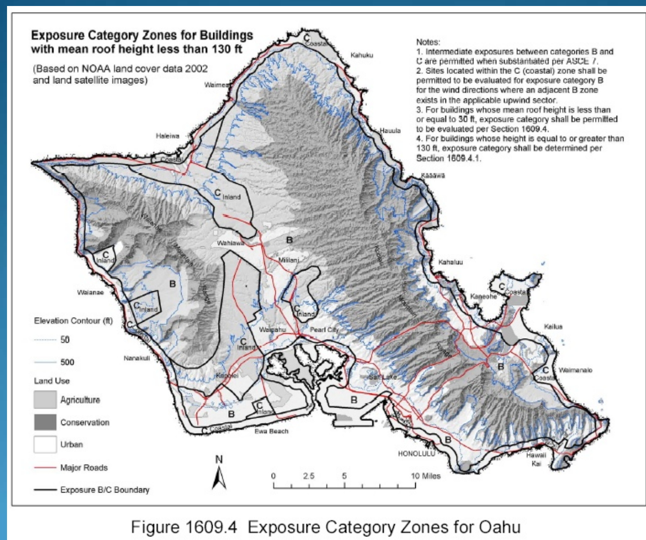

Figure 1609.4 Exposure Category Zones for Oahu

Background on Notes #1 & #2:

The uniform smooth level terrain fetch required for a 75% transition from a B to C (rough to smooth) profile is approximately 10 miles. The uniform rough level terrain fetch for a 75% transition from a C to B profile (smooth to rough) is approximately 1 mile. (See ASCE 7 Commentary C6.5.6.4)

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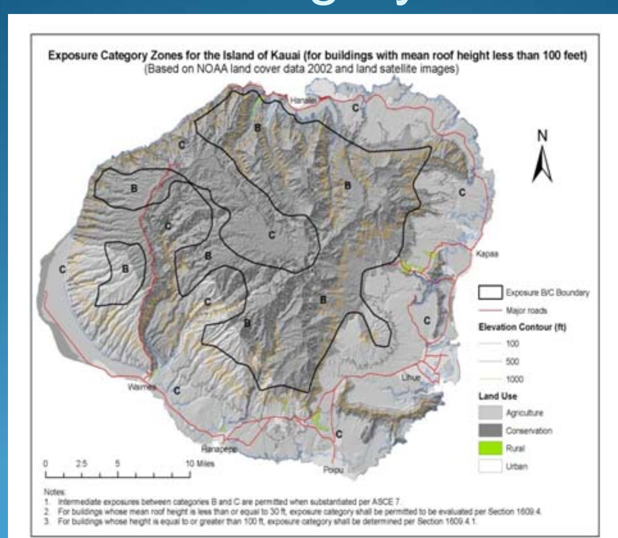
Exposure Category - Kauai



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1611.1 Design Rain Loads

"**1611.1 Design rain loads.** Each portion of a roof shall be designed to sustain the load of rainwater that will accumulate on it if the primary drainage system for that portion is blocked plus the uniform load caused by water that rises above the inlet of the secondary drainage system at its design flow. <u>The design rainfall rate shall be based on the 100-year 1-hour rainfall rate indicated in Figure 1611.1 as published by the National Weather Service or on other rainfall rates determined from approved local weather data."</u>

FIGURE 1611.1—continued
100-YEAR, 1-HOUR RAINFALL (INCHES) HAWAII
For SI: 1 inch = 25.4 mm.
Source: National Weather Service, National Oceanic and Atmospheric Administration, Washington D.C.

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Hawaii Design Maps -Summary

- **<u>Topographic Factor</u>** giving the maximum topographic effect due to mountainous topography
- Tables of **<u>Directionality Factor</u>** that take into account site directional probabilities
- **<u>Exposure</u>** based on Land-cover data developed by the NOAA Coastal Services Center from Landsat Enhanced Thematic Mapper satellite imagery beginning in the year 2000.
- **<u>Effective Wind Speed for Cladding and Components</u>** based on 105 mph basic wind speed adjusted for mountainous topography
- The maps are good for the 2003 – 2009 IBC period of adoptions (i.e., up through 2013), with re-calibration of just the effective wind speed maps to occur thereafter to address upcoming ASCE 7-10 transition to strength-based design criteria.

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End of Module

- Questions?
  - You are *required* to use the Hawaii Wind Maps

Hawaii Wind Design Requirements for Hurricane Shelter and Safe Room Occupancies

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IBC 2006 Amendments:

- **Appendix U – Hawaii Hurricane Sheltering Provisions for New Construction.**

  This Appendix addresses the statutory requirement of §107-25 (4), relating to storm shelters and essential government facilities, and enhanced hurricane protection areas within high occupancy government buildings. It also included provisions for Hawaii residential safe rooms as an economical option in lieu of complete enclosure glazing protection, which partially addresses the requirements of §107-21 and §107-25 (5), hurricane resistive standards for residential construction.
  - U101 Community Storm Shelter Design Criteria
  - U102 Hawaii Residential Safe Room
  - U103 High Occupancy Buildings - Design Criteria for Enhanced Hurricane Protection Areas

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SECTION 421 Community Storm Shelters

Note: Section 421 relating to owner-designated community storm shelters and owner-designated essential facilities, is consistent with the provisions of FEMA Mitigation Interim Policy MRR 2-07-1, citing the ICC-500 consensus standard that is written in code-compatible language approved by ICC. ***This is essentially a voluntary standard that is a prerequisite for projects built with certain federal mitigation grants.***

"421.1 General. In addition to other applicable requirements in this code, community storm shelters and the following specific Occupancy Category IV buildings shall be constructed in accordance with ICC/NSSA-500:

1. Designated earthquake, hurricane or other emergency shelters.
2. Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response.

421.1.1 Scope. This section applies to the construction of storm shelters constructed as separate detached buildings or constructed as safe rooms within buildings for the purpose of providing safe refuge from storms that produce high winds, such as hurricanes. Such structures shall be designated to be hurricane shelters.

421.2 Definitions. The following words and terms shall, for the purposes of this chapter and as used elsewhere in this code, have the meanings shown herein.

COMMUNITY STORM SHELTER. A building, structure, or portions(s) thereof, constructed in accordance with ICC 500-08 ICC/NSSA Standard on the Design and Construction of Storm Shelters and designated for use during a severe wind storm event such as a hurricane."

Hawaii Special Occupancies

- Section 422, Hawaii Residential Safe Room , provides an alternative in lieu of glazing protection of all windows of R-3 residential construction.
- Section 423, Design Criteria for Enhanced Hurricane Protection Areas (EHPA) is applicable to new buildings utilized as shelters and those health-care facilities that should be capable of self-sheltering:
  1. Enclosed and partially enclosed structures whose primary occupancy is public assembly with an occupant load greater than 300.
  2. Health care facilities with an occupant load of 50 or more resident patients, but not having surgery or emergency treatment facilities.
  3. Any other state- and county-owned enclosed or partially enclosed building with an occupant load greater than 5,000.
  4. Hospitals and other health care facilities having surgery or emergency treatment facilities.

Hawaii Residential Safe Room

(Hawaii Amended IBC Section 422 and IRC Section R325)

"422.1.1 Intent and Scope. The intent of the Residential Safe Room is to temporarily provide an enhanced protection area, fully enclosed within a dwelling or within an accessory structure to a residence, which is designed and constructed to withstand the wind pressures, windborne debris impacts, and other requirements of this section. "

"422.2 Site Criteria. Residential Safe Rooms shall not be constructed within areas subject to stream flooding, coastal flooding or dam failure inundation within any of the following areas:

1. FEMA Special Flood Hazard Areas (SFHA) subject to rainfall runoff flooding or stream or flash flooding;
2. Coastal zones "V" or "A" identified in the Flood Insurance Rate Map (FIRM) issued by FEMA for floodplain management purposes, in which the flood hazard are tides, storm surge, waves, tsunamis, or a combination of these hazards;
3. Areas subject to dam failure inundation as determined by the Department of Land and Natural Resources."

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Residential Safe Room Performance Specifications

- **Ventilation:** The room shall be naturally ventilated to allow the enclosure to have approximately one air change every 2 hours. This requirement may be satisfied by 12 square inches of venting per occupant.
- **Exiting:** The room shall be equipped with an inward-swinging door and an impact-protected operable window suitable for a means of alternative exiting in an emergency.
- **Communication:** The safe room shall be equipped with a phone line and telephone that does not rely on a separate electrical power outlet (but it may rely on a Uninterruptible Power Supply (UPS) battery device).
- **Maximum Occupancy:** The safe room is permitted to be used for a maximum occupancy based on at least 15 square feet per person with a maximum of 8 persons in a room of up to 128 square feet of floor area.
- **Readiness:** The safe room shall be fully constructed in all respects. It shall be readily accessible and ready for occupancy to person(s) residing on the property within 2 hours notice.
- **Construction Documents Required:** Construction documents for the installation of the safe room in the residence of the applicant shall be directly prepared by a Hawaii licensed professional structural engineer.

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Minimum Structural Integrity

- The safe room shall be built with a self-sufficient structural system and a complete load path for vertical and lateral loads caused by gravity and wind. The ceiling structure and wall shall be capable of supporting a superimposed debris load of the full weight of any building floors and roof above, but not less than 125 psf.
- The safe room enclosure shall be capable of simultaneously resisting lateral and uplift wind pressures corresponding to a 160 mph 3-second peak gust.
- The building that the safe room is built within shall be assumed to be destroyed by the storm and shall not be taken as offering any protective shielding to the safe room enclosure.
- The safe room shall be anchored to a foundation system capable of resisting the loading.

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Windborne Debris Protection for Residential Safe Rooms

ASTM E 1996 Missile Level Rating	Debris Missile Size	Debris Impact Speed	Protection Type required by the Loss Mitigation Grant Program	Enclosure Wall Ceiling, and Floor Cyclic Air Pressure Testing - maximum inward and maximum outward pressures
D	2 x 4 weighing 9.0 lb. +- 0.25 lb., and with min. length 8 ft. +- 4-inch	50 ft./sec. or at least 34 mph	This is the ASTM standard for enhanced protection applicable to Hawaii Residential Safe Rooms	35 psf inward 45 psf outward

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Cladding for the Safe Room

- Hawaii residents cannot evacuate inland to escape hurricane winds
- Section 422, Hawaii Residential Safe Room , provides an alternative lower cost option in lieu of the IBC requirement for glazing protection of all windows of R-3 residential construction.
- Cladding for the safe room is relatively simple to achieve:
  - Cement Board siding over 5/8” thick structural plywood
  - 3/4” thick structural plywood
  - 22 gage sheet metal
  - The safe room window should have impact protected laminated glazing or a windborne debris protection system.

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Wall Assemblies Complying with Section 422.5.2 Windborne debris impact protection of building enclosure elements

Note: sheathing shall be attached to studs at 6-inches on center edge and field fastening.

Wall Assemblage
¾-inch plywood on wood studs at 16-inches on-center with #8 X 3-inch wood screws at 6-inches o.c.
¾-inch plywood attached to double studs at 16-inches o.c. with #8 X 3-inch wood screws at 6-inches o.c.
8-1/4" cementitious lap siding over 22ga sheet metal attached to 350S162-33 studs at 24" o.c.
8-1/4" cementitious lap siding attached to 350S162-33 studs at 24" o.c. studs with interior 3/4" ply interior sheathing
8-1/4" cementitious lap siding attached to 350S162-33 studs at 24" o.c. with 1/2" interior 22-gage sheet metal composite gypsum wallboard
8-1/4" cementitious lap siding attached to 2 x4 wood studs at 16" o.c. with 1/2" interior 22-gage sheet metal composite gypsum wallboard
8-1/4" cementitious lap siding attached to 2 x4 wood studs at 16" o.c. with 22-gage sheet metal and ½” interior gypsum wallboard
Cementitious lap siding attached to 5/8 inch structural plywood on 2 X 4 wood studs @ 16 inches o/c.
Cementitious-panel siding attached to 5/8 inch structural plywood on 2 X 4 or 362S-137-43 steel studs @ 16 inches o.c.
EFS with ½-inch dens-glass gold exterior sheathing on 362S-137-43 steel studs @ 16 inches and 1/2-inch interior gypboard
Interior or Exterior wall with laterally braced 2 x 4 wood studs with sheathing on either side of 22-gage sheet metal
24 gage steel sheet (50 ksi) on girts
4-inch-thick concrete with reinforcing
6-inch CMU with partial grouting at reinforcing spaced at 24 inches o.c.
8-inch CMU with partial grouting at reinforcing spaced at 24 inches o.c.

SECTION 423 State- and County-owned High Occupancy Buildings - Design Criteria for Enhanced Hurricane Protection Areas

Section 423, Design Criteria for Enhanced Hurricane Protection Areas (EHPA) is applicable to new buildings utilized as shelters and those health-care facilities that should be capable of self-sheltering.

423.1 Intent. The purpose of this section is to establish minimum life safety design criteria for enhanced hurricane protection areas in high occupancy state- and county-owned buildings occupied during hurricanes of up to Saffir Simpson Category 3.

423.2 Scope. This section shall apply to state- and county-owned buildings which are of Occupancy Category III and IV defined by Table 1604.5 and of the following specific occupancies:

1. Enclosed and partially enclosed structures whose primary occupancy is public assembly with an occupant load greater than 300.
2. Health care facilities with an occupant load of 50 or more resident patients, but not having surgery or emergency treatment facilities.
3. Any other state- and county-owned enclosed or partially enclosed building with an occupant load greater than 5,000.
4. Hospitals and other health care facilities having surgery or emergency treatment facilities.

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Kau High School Gymnasium

SECTION 423 State- and County-owned High Occupancy Buildings - Design Criteria for Enhanced Hurricane Protection Areas

425.3 Site Criteria.

425.3.1 Flood and Tsunami Zones. Comply with ASCE 24-05, Flood Resistant Design and Construction, based on provisions for Occupancy Category III.

1. Floor slab on grade shall be 1.5 foot above the Base Flood Elevation of the county's flood hazard map.
2. Locate outside of V and Coastal A flood zones unless justified by site specific analysis or designed for vertical evacuation in accordance with a method approved by the building official.
3. Locate outside of Tsunami evacuation zones unless justified by site specific analysis or designed for vertical evacuation in accordance with a method approved by the building official.

425.3.2 Emergency Vehicle Access. Provide at least one route for emergency vehicle access.

425.3.3 Landscaping and Utility Laydown Impact Hazards.

Trees shall not interfere with the functioning of overhead or underground utility lines, nor cause laydown or falling impact hazard to the building envelope or utility lines.

425.3.4 Adjacent Buildings. Unanchored light-framed portable structures shall be not permitted within 300 feet of the building.

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SECTION 423 State- and County-owned High Occupancy Buildings - Design Criteria for Enhanced Hurricane Protection Areas

425.4 Enhanced Hurricane Protection Area Program Requirements.

425.4.1 Applicable Net Area. At least fifty percent of the net square feet of a facility shall be constructed to qualify as an enhanced hurricane protection area. The net floor area shall be determined by subtracting from the gross square feet the floor area of excluded spaces, exterior walls, columns, fixed or movable objects, equipment or other features that under probable conditions cannot be removed or stored during use as a storm shelter.

425.4.2 Excluded spaces. Spaces such as mechanical and electrical rooms, storage rooms, attic and crawl spaces, shall not be considered as net floor area permitted to be occupied during a hurricane.

425.4.3 Occupancy Capacity. The occupancy capacity shall be determined by dividing the net area of the enhanced hurricane protection area by 15 square feet net floor area per person.

425.4.4 Toilets and hand washing facilities. Provide a minimum of 1 toilet per 50 enhanced hurricane protection area occupants and a minimum of 1 sink per 100 enhanced hurricane protection area occupants.

425.4.5 Accessibility. Where the refuge occupancy accommodates more than 50 persons, provide an ADA-accessible route to a shelter area at each facility with a minimum of 1 wheelchair space for every 200 enhanced hurricane protection area occupants determined per Section 425.4.3.

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SECTION 423 State- and County-owned High Occupancy Buildings - Design Criteria for Enhanced Hurricane Protection Areas

423.5 Design Wind, Rain, and Impact Loads.

423.5.1 Structural Design Criteria. The building Main Wind Force Resisting System and structural components shall be designed per ASCE 7 for a 115 mph minimum peak 3-second gust design speed with a load factor of 1.6, and an Importance Factor for Occupancy Category III.

423.5.2 Windborne Debris Missile Impact for Building Enclosure Elements. Exterior glazing and glazed openings, louvers, roof openings and doors shall be provided with windborne debris impact resistance or protection systems conforming to ASTM E1996-05 Level D, i.e., 9 lb. 2 X 4 @ 50 fps (34 mph).

423.5.3 Cyclic Pressure Loading of Impact Resistive Glazing or Windborne Impact Protective Systems. Resistance to the calculated maximum inward and outward pressure shall be designed to conform to ASTM E1996-05.

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SECTION 423 State- and County-owned High Occupancy Buildings - Design Criteria for Enhanced Hurricane Protection Areas

423.5.4 Windows. All unprotected window assemblies and their anchoring systems shall be designed and installed to meet the wind load and missile impact criteria of this section.

423.5.5 Window Protective Systems. Windows may be provided with permanent or deployable protective systems.

423.5.6 Doors. All exterior and interior doors subject to possible wind exposure and/or missile impact shall have doors, frames, anchoring devices, and vision panels designed and installed to resist the wind load and missile impact criteria

423.5.7 Exterior envelope. The building enclosure, including walls, roofs, glazed openings, louvers and doors, shall not be perforated or penetrated by windborne debris, as determined by compliance with ASTM E1996-05 Level C.

423.5.8 Parapets. Parapets shall satisfy the wind load and missile impact criteria of the exterior envelope.

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423.5.9 Roofs

423.5.9.1 Roof Openings. Roof openings (e.g., HVAC fans, ducts, skylights) shall be provided with protection for the wind load and missile impact criteria.

423.5.9.2 High Wind Roof Coverings. Roof coverings shall be specified and designed according to the latest ASTM Standards for high wind uplift forces.

423.5.9.3 Roof Drainage. Roofs shall have adequate slope, drains and overflow drains or scuppers sized to accommodate 100-year hourly rainfall rates in accordance with Section 1611.1, but not less than 2-inches per hour for 6 continuous hours.

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423.6 Ventilation

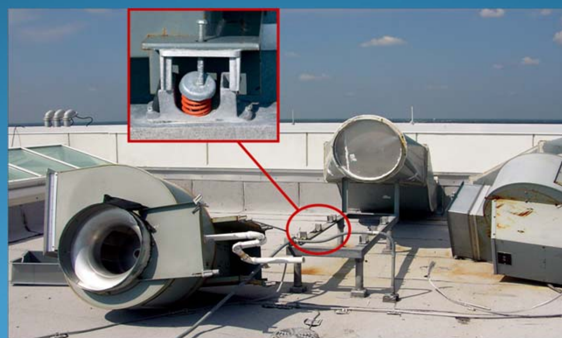
423.6.1 Mechanical ventilation. Air intakes and exhausts shall be designed and installed to meet the wind load and missile impact criteria.

423.6.2 HVAC Equipment anchorage. HVAC equipment mounted on roofs and anchoring systems shall be designed and installed to meet the wind load criteria. Roof openings for roof-mounted HVAC equipment shall have a 12- inch-high curb designed to prevent the entry of rain water.

Secure External Components

Debris protection should be provided for mounted building equipment.

Such equipment should also be properly secured.



Here, an HVAC system has been blown away by high winds. (Photo from FEMA)

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Emergency Power

423.7 Standby Electrical System Capability. Provide a standby emergency electrical power system, which shall have the capability of being connected to an emergency generator or other temporary power source.

423.7.1 Emergency Generator. When emergency generators are preinstalled, the facility housing the generator, permanent or portable, shall be an enclosed area designed to protect the generators from wind and missile impact.

423.9 Maintenance

423.9 Maintenance. The building shall be periodically inspected every

three years and maintained by the owner to ensure structural integrity and compliance with this section. A report of inspection shall be furnished to State Civil Defense.

423.10 Compliance Re-certification when Altered, Deteriorated, or

Damaged. Alterations shall be reviewed by a Hawaii-licensed structural

engineer to determine whether any alterations would cause a violation of this section. Deterioration or damage to any component of the building shall require an evaluation by a Hawaii-licensed structural engineer to determine repairs necessary to maintain compliance with this section."

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Wind Criteria for Hurricane Safe Rooms and Shelters

Type B Shelter (expectation for existing shelters)	Type A Shelter	**Residential Safe Room**	**Building with an EHPA**	Essential Facility with COOP
~250 years	500 years	**1,000 + years**	**1,000 + years**	10,000 years
80 mph peak gust design speed Load factor of 1.6 Importance Factor of 1.15 Results in a Strength Capacity ≥108 mph peak gust	95 mph peak gust design speed Load factor of 1.6 Importance Factor of 1.15 Results in a Strength Capacity ≥130 mph peak gust	**160 mph peak gust design speed Load factor of 1.0 Importance Factor of 1.0 Results in a Strength Capacity ≥160 mph peak gust**	**115 mph peak gust design speed Load factor of 1.6 Importance Factor of 1.15 Results in a Strength Capacity ≥156 mph peak gust**	140 mph peak gust design speed Load factor of 1.6 Importance Factor of 1.15 Directionality of 1.0 Results in a Strength Capacity ≥190 mph peak gust
Without opening protection, provided only interior rooms are used; or Glazing to resist ASTM E1996-05 Level A 2g steel balls at 130 fps (90 mph) Design for interior pressure	Walls and Glazing must resist ASTM E1996-05 Level C 4.5 lb. 2 X 4 @ 40 fps (27 mph) Design for interior pressure	**Walls and Glazing must resist ASTM E1996 -05 Level D 9 lb. 2 X 4 @ 50 fps (34 mph)**	**Walls and Glazing must resist ASTM E1996 -05 Level D 9 lb. 2 X 4 @ 50 fps (34 mph) Design for interior pressure**	Walls and Glazing must resist ASTM E1996-05 Level E 9 lb. 2 X 4 @ 80 fps (55 mph) Design for interior pressure

Conclusions

- Section 422, Hawaii Residential Safe Room , provides an alternative in lieu of glazing protection of all windows of R-3 residential construction.
- Section 423, Design Criteria for Enhanced Hurricane Protection Areas (EHPA) is applicable to new buildings utilized as shelters and those health-care facilities that should be capable of self-sheltering:
  1. Enclosed and partially enclosed structures whose primary occupancy is public assembly with an occupant load greater than 300.
  2. Health care facilities with an occupant load of 50 or more resident patients, but not having surgery or emergency treatment facilities.
  3. Any other state- and county-owned enclosed or partially enclosed building with an occupant load greater than 5,000.
  4. Hospitals and other health care facilities having surgery or emergency treatment facilities.

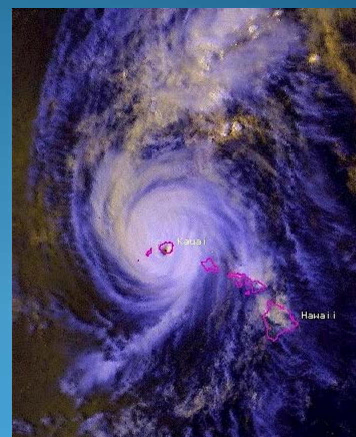
Guidance on the size of a safe room (revised text to be in the next state code)

- Size of safe room. The safe room shall be designed to provide a minimum of 15 square feet per person in a room which does not need to exceed 120 square feet (11 m^2) of floor area.

End of Module

- Questions?

The State Building Code and Cladding Standards for Wind and Windborne Debris



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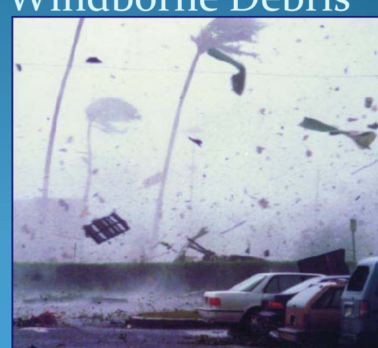
Wind Hazard Effects

Wind damages buildings in two key ways.

Wind Forces

Windborne Debris



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The State Building Code and Cladding Standards for Wind and Windborne Debris

- **Glazing and Nonstructural Design and Protection Requirements**
- **Hawaii Residential Safe Room**

Hawaii is classified in the IBC as a hurricane-prone region *and* a windborne debris region

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Two Parts to Wind Design: Structural and Nonstructural

First, the Main Wind Force Resisting System, or MWFRS is designed to structural integrity. This includes the structural components like wall framing, floor and roof diaphragms, and shear walls —elements that transmit the wind forces acting on the structure of the building.

Second, the wind design must address Components and Cladding, or C&C, such as roof sheathing, roof covering, exterior siding, windows, doors, soffits, fascias, and chimneys. This is where an architect, supplier, or builder will (or should) consult design pressure tables and determine the requirements for different building elements, including the windows.

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A variety of nonstructural exterior cladding and components to consider in wind design

ARCHITECTURAL	EQUIPMENT
• Façades and Cladding Systems • Roofing • Parapets • Chimneys • Glass windows • Attachments (signs, antennae,etc) • Ornaments • Canopies • Doors	• Rooftop and Site equipment • Air conditioning • Electrical generator • Communicatons • Power

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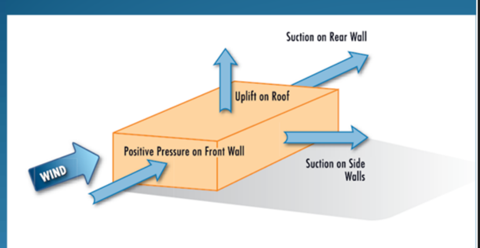
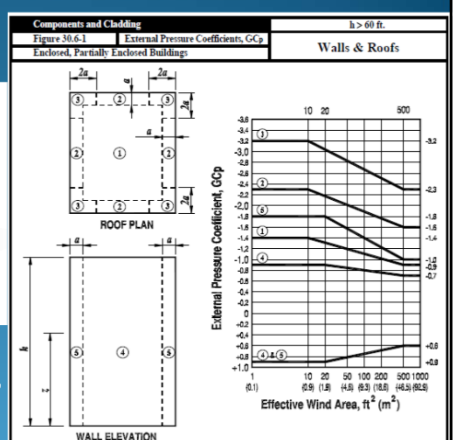
Designing the Envelope



- Example of C&C combined Gust - Pressure Coefficients for buildings taller than 60 ft.
- Note zones of higher pressure at corners or discontinuities
- *Coefficients vary with the size of element*



Notes:

1. Vertical scale denotes GC_p to be used with appropriate q_z or q_h.
2. Horizontal scale denotes effective wind area A, in square feet (square meters).
3. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
4. Use q_z with positive values of GC_p and q_h with negative values of GC_p.
5. Each component shall be designed for maximum positive and negative pressures.
6. Coefficients are for roofs with angle $\theta \le 10°$. For other roof angles and geometry, use GC_p values from Fig. 30.4-2A, B and C and attendant q_h based on exposure defined in Section 26.7.
7. If a parapet equal to or higher than 3 ft (0.9m) is provided around the perimeter of the roof with $\theta \le 10°$, Zone 3 shall be treated as Zone 2.
8. Notation:
   - a: 10 percent of least horizontal dimension, but not less than 3 ft (0.9 m).
   - h: Mean roof height, in feet (meters), except that eave height shall be used for $\theta \le 10°$.
   - z: height above ground, in feet (meters).
   - θ: Angle of plane of roof from horizontal, in degrees.

Summary of Cladding Standards for Wind and Windborne Debris

- Cladding and Components: Use the Effective Velocity Wind Maps and the Exposure Maps as reference values in Performance Specifications and Prescriptive Design Tables
- Glazing Protection from Windborne Debris is Based on Occupancy Category
- Roof decks and roof coverings shall be designed for wind loads in accordance with Chapter 16 and Sections 1504.2, 1504.3 and 1504.4.
- 2006 IBC prohibits of the use of aggregate used as surfacing on built-up roofs, and gravel and stone ballast on roofs in hurricane-prone region

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Specify the explicit wind rating for Window Systems

- Window frames to comply with AAMA/WDMA/CSA* 101/I.S.2/A440-05 Standard/Specification for Windows, Doors, and Unit and ASTM E330 Standard Test Method for Structural Performance of Exterior Windows, Doors, Skylights and Curtain Walls by Uniform Static Air Pressure Difference. In this standard, the window must be engineered and tested to 150% of the peak design wind pressure without failure.
- Glazing to be specified to meet the design wind pressure per ASTM E1300 Standard Practice for Determining Load Resistance of Glass in Buildings, which should provide 99.2% reliability for that pressure.
- In the Hurricane Prone Region, specify compliance with ASTM E1996 to incorporate windborne debris protection
- **Key Point:** It is cautioned that omitting these specifications essentially means there would be no explicit verification of the suitability of the product to meet its intended use on the project.

*** American Architectural Manufacturers Association (AAMA), the Window Manufacturers Association (WDMA), and the Canadian Standards Association (CSA)**

Wind Loads on Glass

2404.1 Vertical glass. Glass sloped 15 degrees (0.26 rad) or less from vertical in windows, curtain and windowwalls, doors and other exterior applications shall be designed to resist the wind loads in Section 1609 for components and cladding. Glass in glazed curtain walls, glazed storefronts and glazed partitions shall meet the seismic requirements of ASCE 7, Section 13.5.9. **The load resistance of glass under uniform load shall be determined in accordance with ASTM E 1300.**

2404.2 Sloped glass

2404.3 Wired, patterned and sandblasted glass

2404.4 Other designs

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Design Pressure on the Structure or its Components

p, is a net combination of external and internal pressures

$$p = qGCp - qGCp_i$$

- q is the computed velocity-related pressure contribution.
- GCp is the gust effect and ***external*** pressure coefficient that varies with structural geometry and location on the structure. These values are shown in figures.
- GCpi is the gust effect and ***internal*** pressure coefficient that varies the degree of enclosure of the structure, and are given in a table. Even enclosed buildings have some amount of internal pressure.

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Hawaii Wind Speed (before and after topographic effects)

- Per IBC 2006 and ASCE 7-05, V = 105 mph 3-second gust
- The Hawaii State and Local County Building Codes require the use of the Hawaii topographic effects
- Engineers utilize the K_{zt} and K_d factor maps for design and need not use the effective windspeed maps
- Architects and Specification writers can utlize the more approximate effective velocity V_{eff} maps to specify products, that already incorporate the effect of topographic amplification, resulting in effective windspeeds greater than 105 mph.

Specify Wind Performance Criteria for Components with the Effective Velocity and Exposure Category

- The $V_{effective}$ values and Exposure maps can be used for performance-specified building components and cladding, as well as when using almost any prescriptive design tables and existing reference standards and simplified methods based on wind speed tables

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1609.3.2 Effective basic wind speed conversion.

For the Simplified Wind Load Method of Section 1609.6, Wind uplift connectors of Section 2308.10.1, the provisions of ASCE Section 6.4, and the AF & PA Wood Frame Construction Manual for One- and Two-Family Dwellings, the basic wind speed value used for determination of the wind loads, shall be the Effective Basic Wind Speed, Veff , determined by Figure 1609.1.1.1, which adjusts the basic wind speed for special topographic wind regions of Oahu.

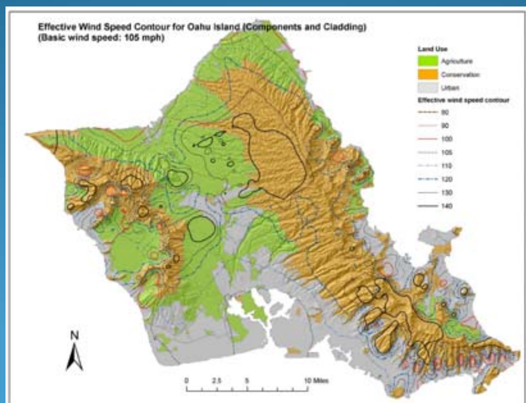

Figure 1609.1.1.1 Effective Basic Wind Speed, V_{eff}, for Components and Cladding for Buildings less than 60 feet tall.

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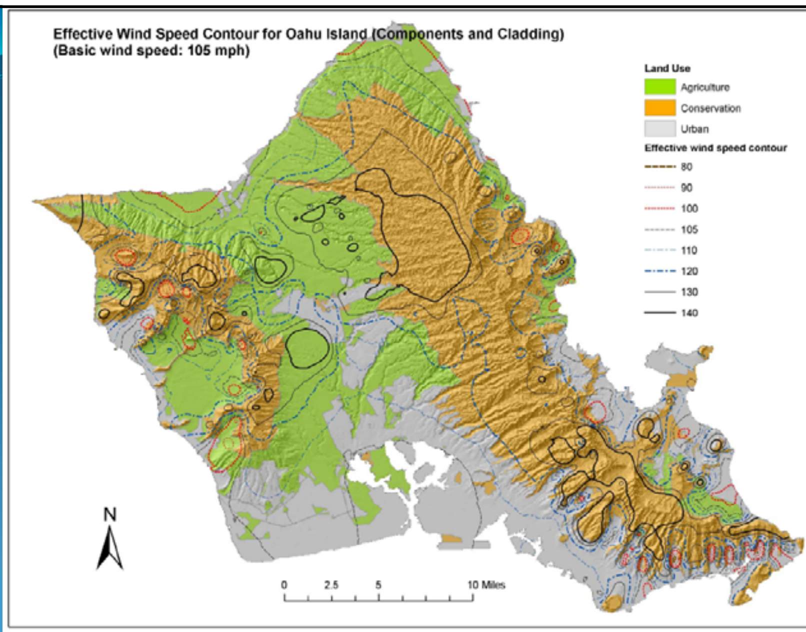

Figure 1609.1.1.1 Effective Basic Wind Speed, V_{eff}, for Components and Cladding for Buildings less than 60 feet tall.

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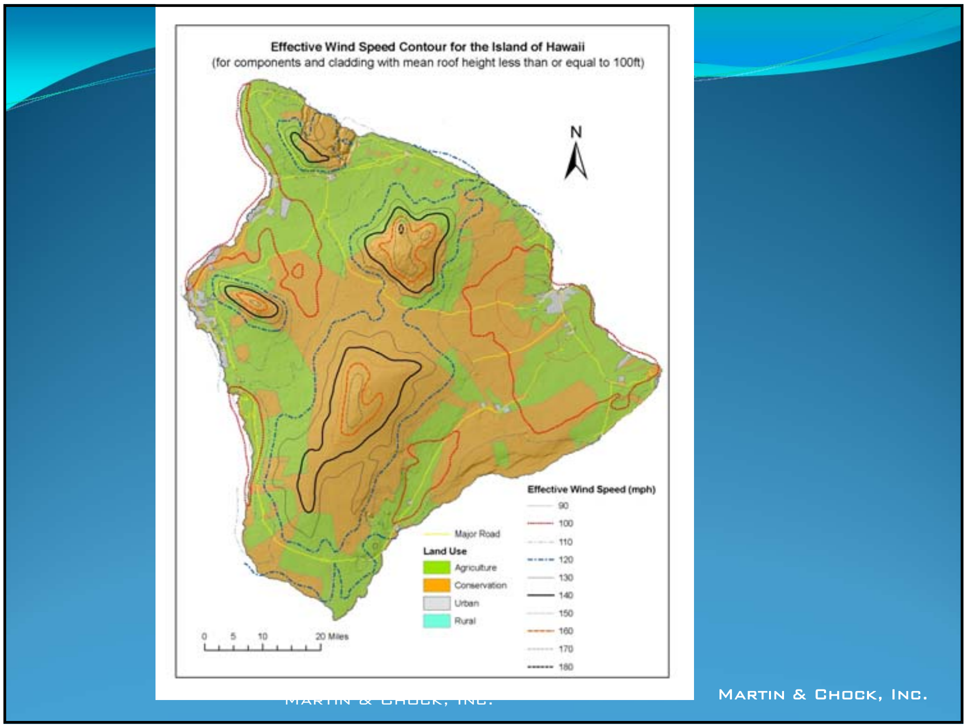
Effective Wind Speed Contour for the Island of Hawaii
(for components and cladding with mean roof height less than or equal to 100ft)
N
Effective Wind Speed (mph)
90
100
110
120
130
140
150
160
170
180
Major Road
Land Use
Agriculture
Conservation
Urban
Rural
0 5 10 20 Miles
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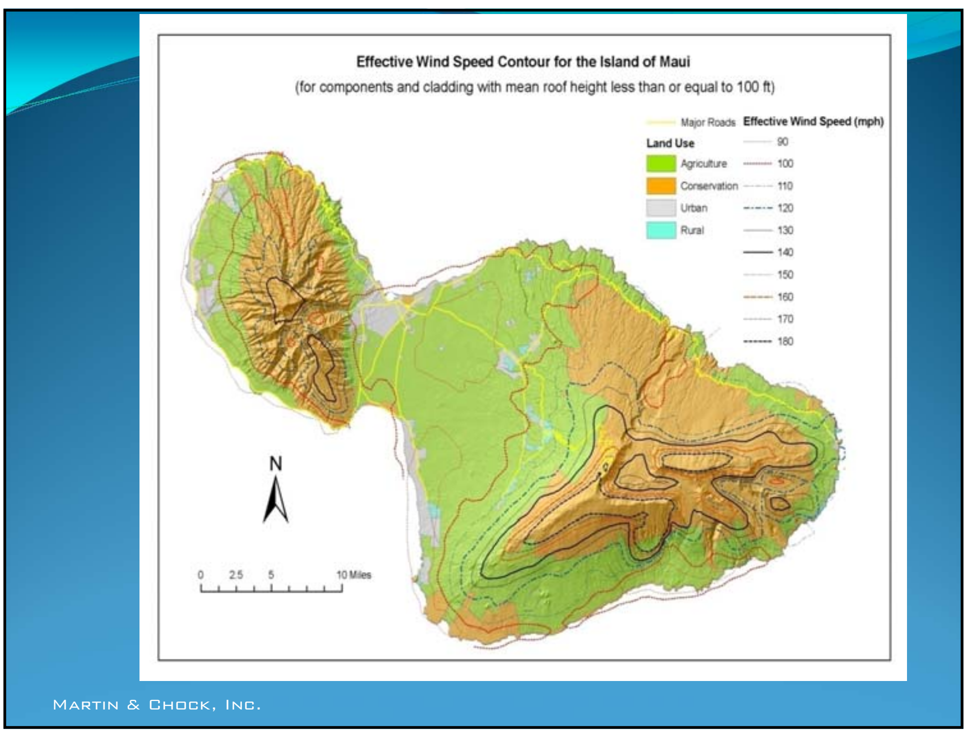
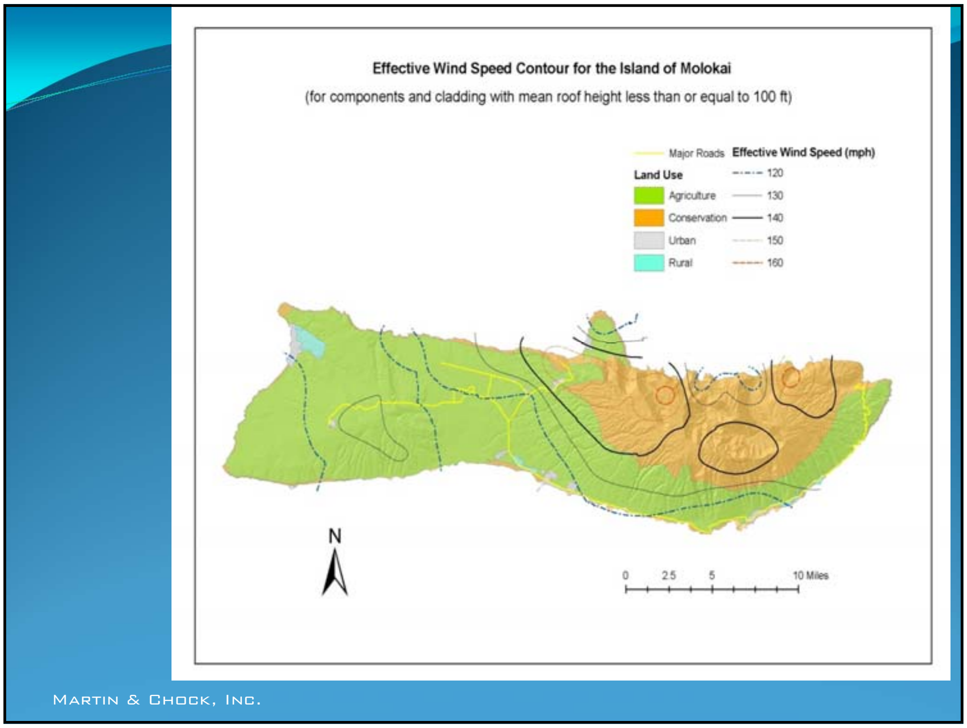
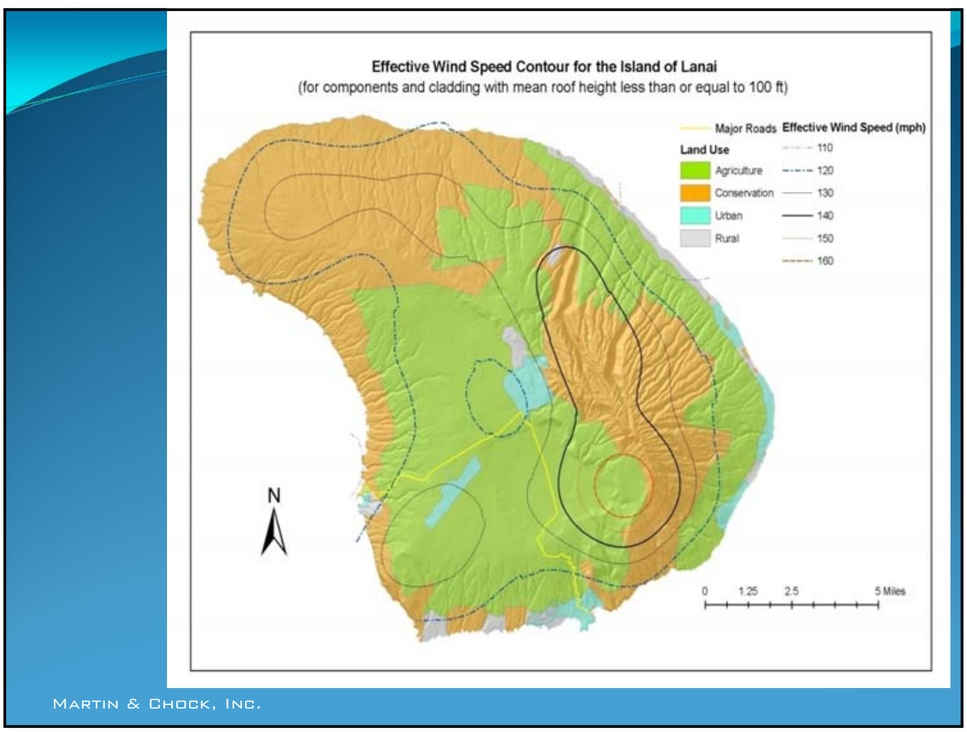

Effective Wind Speed Contour for the Island of Maui
(for components and cladding with mean roof height less than or equal to 100 ft)
Major Roads
Effective Wind Speed (mph)
Land Use
Agriculture
Conservation
Urban
Rural
90
100
110
120
130
140
150
160
170
180
N
0 2.5 5 10 Miles
Martin & Chock, Inc.


Effective Wind Speed Contour for the Island of Molokai
(for components and cladding with mean roof height less than or equal to 100 ft)
Major Roads
Effective Wind Speed (mph)
Land Use
Agriculture
Conservation
Urban
Rural
120
130
140
150
160
N
0 2.5 5 10 Miles
MARTIN & CHOCK, INC.


Effective Wind Speed Contour for the Island of Lanai
(for components and cladding with mean roof height less than or equal to 100 ft)
Major Roads
Effective Wind Speed (mph)
Land Use
Agriculture
Conservation
Urban
Rural
110
120
130
140
150
160
N
0 1.25 2.5 5 Miles
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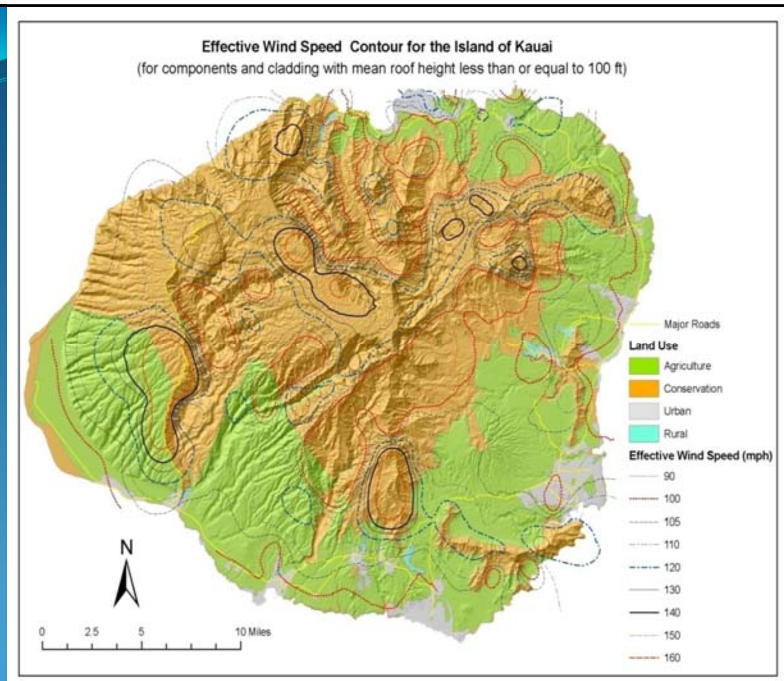

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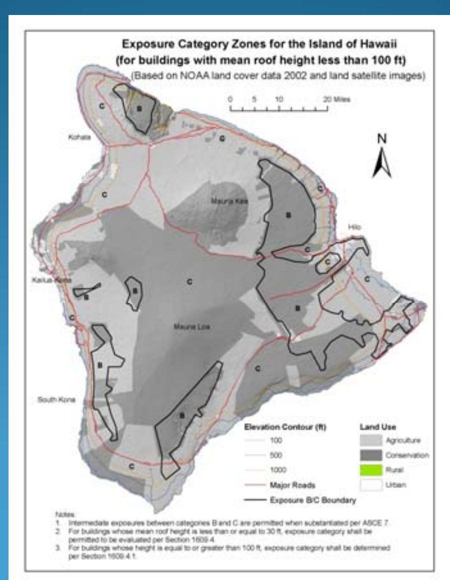
Exposure Category - Hawaii



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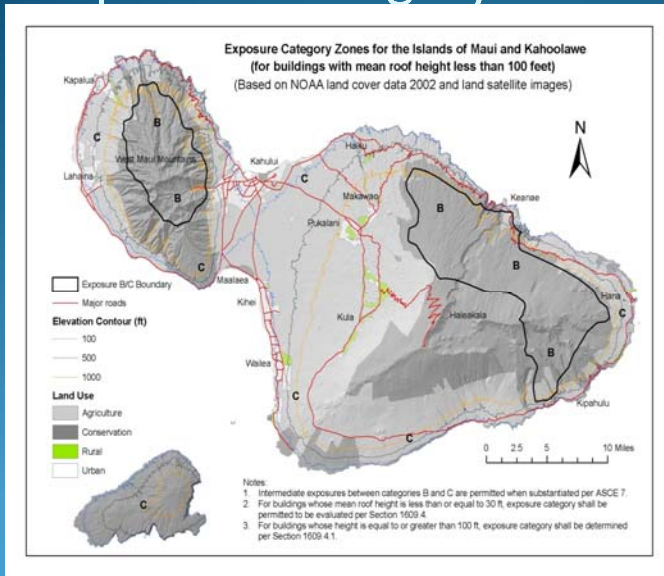
Exposure Category - Maui



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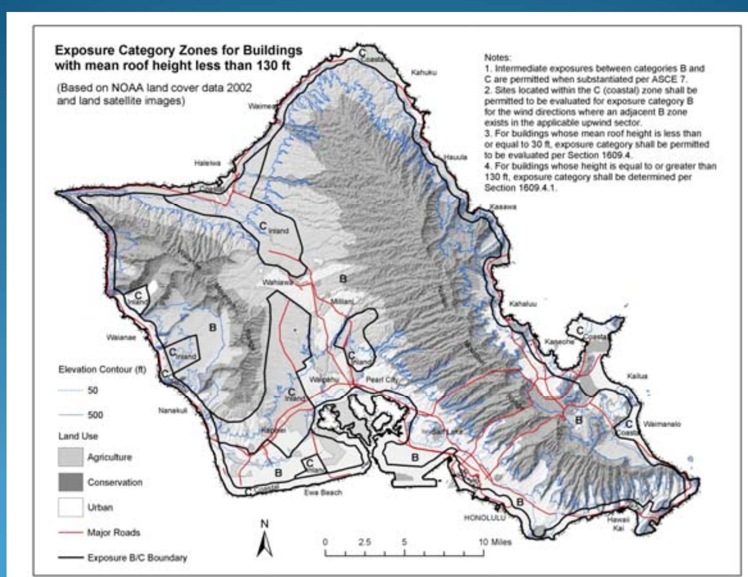
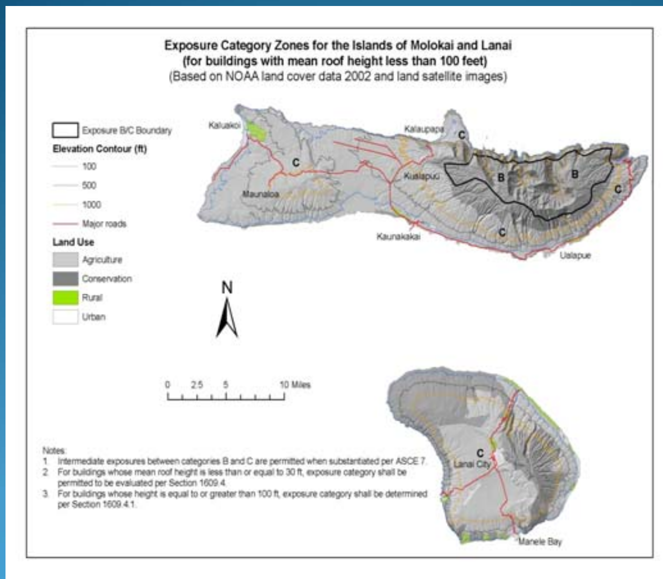
Exposure Category - Oahu



Exposure Category - Molokai and Lanai



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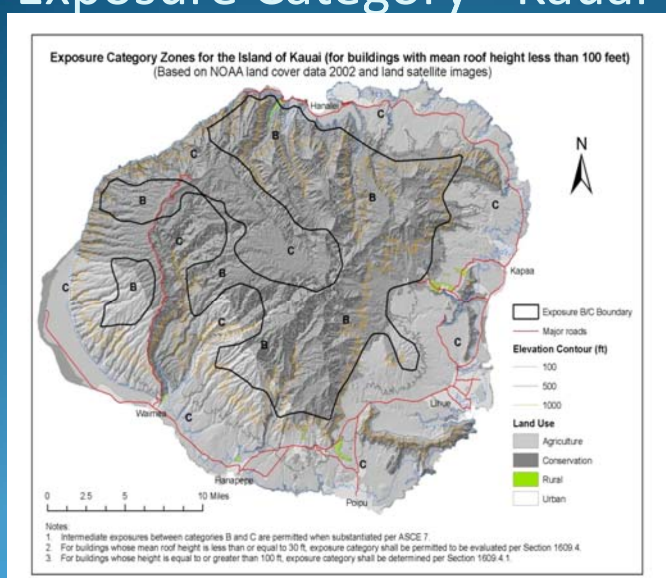
Exposure Category - Kauai



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Glazing Protection from Windborne Debris

- Applicable to any portion of a building up to 60 ft. height and within 30 ft. above any aggregate surface roofs located within 1,500 feet of the building

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ASCE 7 and IBC 2006 Windborne Debris Requirements

- Windborne debris regions are established for areas of the country with hurricane risk based on distance from the coastline. Landfalling hurricanes on the continental United States lose intensity of wind speed once they are no longer over the ocean energy source. The distance for the windborne debris region varies, but it is generally in the range of 50 to 150 miles from the coastline.
- For the continent, ASCE selected the 120 mph 3-second gust wind hazard contour as an approximation of the coastal region subject to debris from landfalling hurricanes. That is, the basis was distance from the coast and *not the wind speed value*.
- In Hawaii, the islands are not nearly large enough to isolate hurricane systems from their oceanic source of energy. Moreover, hurricane systems can pass to any side of the islands and the windfield of hurricanes is large enough to generate hurricane force winds on land even without the direct passage of the eye of the storm overhead.
- Thus, Hawaii statewide was designated as a windborne debris region in recognition of the physics of the tropical cyclone environment being different for Hawaii than the mainland.

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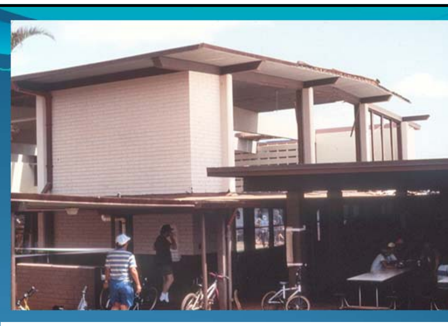
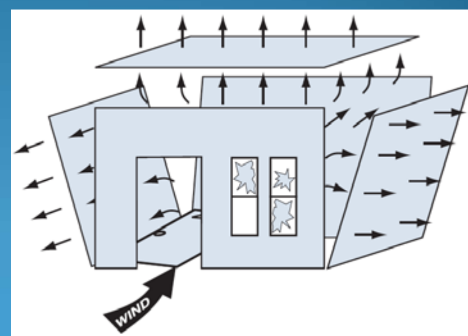
Breaches Can Create Progressive Failure

- Breaches of the envelope will lead to a build up of internal pressure.
- Internal Pressure changes can cause small leakages to become larger breaches of the building envelope.
- Large breaches can undermine a building's structural system and destroy interior valuables.





Design and Construction Guidance for Community Safe Rooms (FEMA 361 – Second Edition, August 2008). http://www.fema.gov/library/viewRecord.do?id=1657

Hawaii State Amendments to IBC 2006 for Hurricane Resilience

- IBC 2006 requires opening protection for all windows and doors in all Hurricane Zones up to 60 ft height (including Hawaii)
- Hawaii State Amendment provides option of including safe room in home in lieu of protecting all windows, which is capable of housing all occupants, and has other amendments that make opening protection requirements based on Occupancy Category.

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Glazing Protection per IBC 2006 - Hawaii Amendments

Research by the HHRF indicated that glazing protection for all windows in single family residences did not have a high rate of return on investment due to the relatively moderate probability of hurricanes in Hawaii

SEAOH and SCD formulated an amendment for exceptions in certain structural occupancies that still maintains life safety protection.

The State Building Code amendments to the IBC 2006 reflect the fact that structural design is feasible for partially enclosed conditions that accommodate the assumption of glazing breakage and internal pressurization.

The exceptions vary with the Occupancy Categories in Chapter 16 of the IBC, not the architectural occupancies of Chapter 4.

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Building Code Requirements

- Hawaii State Building Code
  - Based on IBC-2006 with amendments
  - Provide opening protection, or
  - Design for internal pressurization (ballooning and deflation) if partially enclosed
  - If without opening protection, for single familly residences that are partially enclosed, also provide a Safe Room for occupants to shelter-in-place (costs about $1,000 to $2,000 in construction costs)
  - Median single-family home presently about $675,000.

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Hawaii Amendment for openings

1609.1.2.1 Building with openings. Where glazing is assumed to be an opening in accordance with Section 1609.1.2, the building shall be evaluated to determine if the openings are of sufficient area to constitute an open or partially enclosed building as defined in ASCE 7. Open and partially enclosed buildings shall be designed in accordance with the applicable provisions of ASCE 7. **Partially enclosed Occupancy R-3 buildings shall also include a residential safe room in accordance with Section 422, Hawaii Residential Safe Room.**

What is Partially Enclosed

- In the hurricane context, an unprotected window is an opening (it becomes an opening when it is broken by windborne debris). A fixed louver is an opening. A door is not an opening.
- Partially Enclosed conditions occur when there is an inbalance of openings that prevents inflow and outflow to equilibrate. So, it is based on the geometric distribution of the openings on the exterior walls.

Partially Enclosed Building

A building that complies with both of the following conditions:
1. The total area of openings in a wall that receives positive external pressure exceeds the sum of the areas of openings in the balance of the building envelope (walls and roof) by more than 10 percent.

2. The total area of openings in a wall that receives positive external pressure exceeds 4 ft^2 (0.37 m2)or 1 percent of the area of that wall, whichever is smaller, and the percentage of openings in the balance of the building envelope does not exceed 20 percent.

Nevertheless, Local Counties Made Modifications to the Wind-Borne Debris Region Definition

- Honolulu, Kauai and Hawaii Counties: "WIND-BORNE DEBRIS REGION" means portions of hurricane-prone regions that are within one (1) mile (1.61 km) of the coastal mean high water line where the **effective** basic wind speed is 110 mph (48 *m/s)* or greater; or portions of hurricane-prone regions where the **effective** basic wind speed is 120 mph (53 *m/s)* or greater."
- Honolulu, Kauai, and Hawaii Counties have created a complication in enforcement that uses the effective wind speed contours to determine where protection is required. Maui then decided to follow the group.

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Nevertheless, Local Counties Made Modifications to the Wind-Borne Debris Region Definition

- Maui used the original language: "WIND-BORNE DEBRIS REGION" means portions of hurricane-prone regions that are within one (1) mile (1.61 km) of the coastal mean high water line where the basic wind speed is 110 mph (48 *m/s)* or greater; or portions of hurricane-prone regions where the basic wind speed is 120 mph (53 *m/s)* or greater; or Hawaii.“

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Special Honolulu Amendment

Occupancy R-4 Residential Assisted Living Facilities and Occupancy R-3 (including their components and cladding) designed as a partially enclosed structure shall also include a residential safe room in accordance with Article 13, Hawaii Residential Safe Room.

Glazing Protection from Windborne Debris is Based on Occupancy Category

(Applicable to any portion of a building up to 60 ft. height and within 30 ft. above any aggregate surface roofs located within 1,500 feet of the building)

- Occupancy I: Buildings and other structures that represent a low hazard to human life in the event of failure: Glazing protection not required
- Occupancy II: Not Required if it is Structurally Designed for Internal Pressure, but then Residential R-3 Buildings (if partially enclosed) shall also have a Residential Safe Room

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Glazing Protection from Windborne Debris is Based on Occupancy Category

- Occupancy III: Buildings and other structures that represent a substantial hazard to human life in the event of failure. Glazing protection required for :
  a. Covered structures whose primary occupancy is public assembly with an occupant load greater than 300.
  b. Health care facilities with an occupant load of 50 or more resident patients, but not having surgery or emergency treatment facilities.
  c. Any other public building with an occupant load greater than 5,000.
- Occupancy IV: Buildings and other structures designated as essential facilities: Glazing protection required

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Windborne Debris Impact Test Protocols

- **ASTM E1996 "Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors and Storm Shutters Impacted by Windborne Debris in Hurricanes**
  - small missile
  - large missile
- **ASTM E1886 "Standard Test Method for Performance of Exterior Windows, Curtain Walls, Doors and Storm Shutters Impacted by Missiles and Exposed to Cyclic Pressure Differentials"**
  - 4500 load cycles under inward acting pressure
  - 4500 load cycles under outward acting pressure
  - Cycles have a min. duration of 1 sec. and max. duration of 3 sec. for various ranges of pressure

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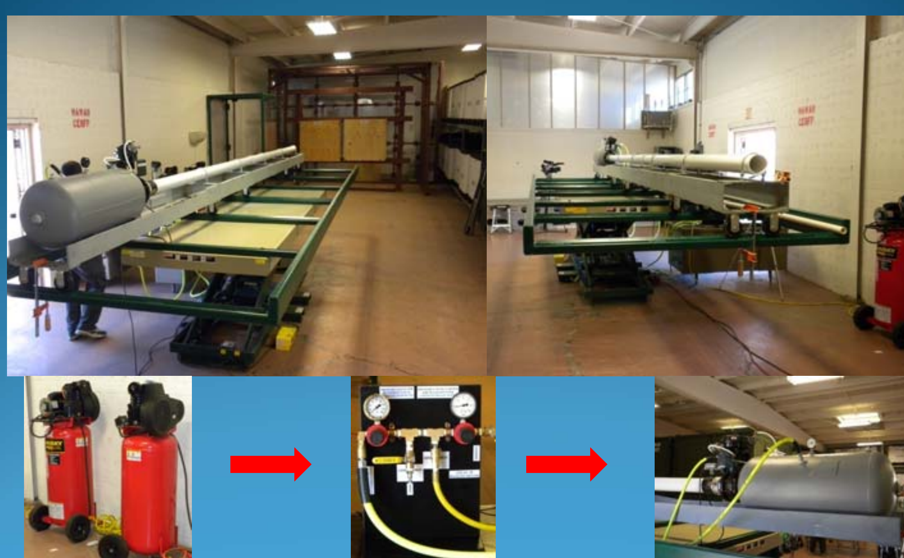
Wind-borne Debris Cannon



Windborne Debris Impact Test Intent

Large Missiles:

Timbers, roof tiles, sheet metal, bricks

Fly or tumble near ground

Impact speed up to 1/3 to 1/2 of V_{eff}

Small Missiles:

Roof gravel, glass particles,

Fly at rooftop elevations

Impact speed up to 90% of V_{eff}

Large missile test:

4.5 - 15 lb 2x4 timber impacting between 0.10 and 0.55 of the basic wind speed

Small missile test:

solid steel balls having a mass of 2 gm impacting between 0.40 and 0.75 of the basic wind speed (3-sec gust)

ASTM STANDARD E1996 Standard Specification for Performance of Exterior Windows, Curtain Walls, Doors and Storm Shutters Impacted by Windborne Debris in Hurricanes

Level of Protection	Enhanced Protection (essential facilities)		**Basic Protection**		Unprotected	
Assembly Height	≤30 ft	> 30 ft	≤ 30 ft	> 30 ft	≤ 30 ft	> 30 ft
Wind Zone 1 (Hawaii)	D	D	**C**	**A**	None	None
Wind Zone 2	*D*	*D*	*C*	*A*	*None*	*None*
Wind Zone 3	*E*	*D*	*D*	*A*	*None*	*None*
Wind Zone 4	*E*	*D*	*D*	*A*	*None*	*None*

Windborne Debris Testing Device built per Hawaii State Legislature requirement

importance category of the building

Test (3) specimens

Small Missile Level A:

- 2 gram spherical steel balls
- impacting at 130 ft/sec (89 mph)
- Thirty impacts per specimen

Large Missile Level	2 X 4 Missile	Impact Speed
B	2.0 lbs. @ 1'-9"	50 fps (34 mph)
C	**4.5 lbs. @ 4'-0"**	**40 fps** (27 mph)
D	9.0 lbs. @ 8'-0"	50 fps (34 mph)
E	9.0 lbs. @ 8'-0"	80 fps (55 mph)

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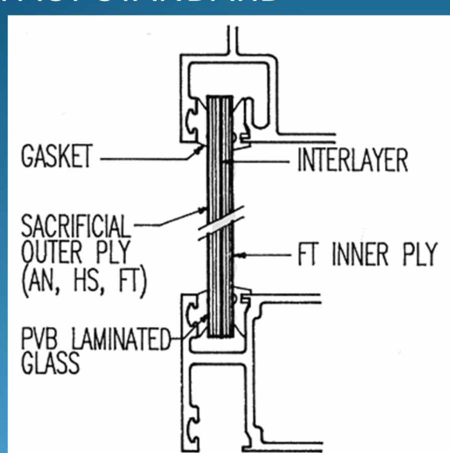
TYPICAL GLAZING SYSTEM DESIGNS THAT MEET IMPACT STANDARD



Impact Protective Systems are also an option

Impact-Resistant Glazing

Glazing must be able to accommodate windborne debris impacts.

Impact resistant glazing will continue to hold wind pressure after a debris strike

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Exceptions to Glazing Protection

1. Wood structural panels with a minimum thickness of 7/16 inch (11.1 mm) and a maximum panel span of 8 feet (2438 mm) shall be permitted for opening protection in one- and two-story buildings. Panels shall be precut so that they shall be attached to the framing surrounding the opening containing the product with the glazed opening. Panels shall be secured with the attachment hardware provided. Attachments shall be designed to resist the components and cladding loads determined in accordance with the provisions of ASCE 7. Attachment in accordance with Table 1609.1.2 is permitted for buildings with a mean roof height of 33 feet (10 058 mm) or less where wind speeds do not exceed 130 mph (57.2 m/s).

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Exceptions to Glazing Protection

2. Glazing in Occupancy Category I buildings as defined in Section 1604.5, including greenhouses that are occupied for growing plants on a production or research basis, without public access shall be permitted to be unprotected.

3. Glazing in Occupancy Category II, III or IV buildings located over 60 feet (18 288) mm) above the ground and over 30 feet (9144 mm) above aggregate surface roofs located within 1,500 feet (458 m) of the building shall be permitted to be unprotected.

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Exceptions to Glazing Protection

4. **Glazing in Occupancy Category II and III buildings that can receive positive external pressure in the lower 60 feet (18 288 mm)** ***shall be assumed to be openings unless such glazing is impact-resistant or protected with an impact-resistant system.***

Exception: Glazing in Occupancy Category III buildings defined by Table 1604.5 of **the following occupancies shall be provided with windborne debris protection:**

a. Covered structures whose primary occupancy is public assembly with an occupant load greater than 300.

b. Health care facilities with an occupant load of 50 or more resident patients, but not having surgery or emergency treatment facilities.

c. Any other public building with an occupant load greater than 5,000.

Glazing Protection from Windborne Debris - Summary

- Applicable to any portion of a building up to 60 ft. height and within 30 ft. above any aggregate surface roofs located within 1,500 feet of the building
- Occupancy I Buildings and other structures that represent a low hazard to human life in the event of failure: Glazing protection not required
- **Occupancy II Not Required if it is Structurally Designed for Internal Pressure, but Residential R-3 Buildings shall also have a Residential Safe Room**
- Occupancy III Buildings and other structures that represent a substantial hazard to human life in the event of failure. Glazing protection required for :
  - a. Covered structures whose primary occupancy is public assembly with an occupant load greater than 300.
  - b. Health care facilities with an occupant load of 50 or more resident patients, but not having surgery or emergency treatment facilities.
  - c. Any other public building with an occupant load greater than 5,000.
- Occupancy IV Buildings and other structures designated as essential facilities: Glazing protection required per large missile up to 60 ft above grade

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With the Hawaii Amendment, openings (glazing without protection) and Louvers can be accommodated by the structural design

1609.1.2.1 Building with openings. Where glazing is assumed to be an opening in accordance with Section 1609.1.2, the building shall be evaluated to determine if the openings are of sufficient area to constitute an open or partially enclosed building as defined in ASCE 7. Open and partially enclosed buildings shall be designed in accordance with the applicable provisions of ASCE 7. **Partially enclosed Occupancy R-3 buildings shall also include a residential safe room in accordance with Section 422, Hawaii Residential Safe Room.**

[R-3 residential occupancies include those that do not contain more than two dwelling units, Adult facilities that provide accommodations for five or fewer persons of any age for less than 24 hours, Child care facilities that provide accommodations for five or fewer persons of any age for less than 24 hours, Congregate living facilities with 16 or fewer persons]

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With the Hawaii Amendment, openings (glazing without protection) and Louvers can be accommodated by the structural design

1609.1.2.2 Louvers. Louvers protecting intake and exhaust ventilation ducts *not assumed to be open* that are located within 30 ft (9144 mm) of grade shall meet requirements of an approved impact-resisting standard or the Large Missile Test of ASTM E 1996.

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Summary of Cladding Standards for Wind and Windborne Debris

- Cladding and Components: Use the Effective Velocity Wind Maps and the Exposure Maps as reference values in Performance Specifications and Prescriptive Design Tables
- Roof decks and roof coverings shall be designed for wind loads in accordance with Chapter 16 and Sections 1504.2, 1504.3 and 1504.4.
- 2006 IBC prohibits of the use of aggregate used as surfacing on built-up roofs, and gravel and stone ballast on roofs in hurricane-prone regions (Hawaii)

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Roof Requirements

- Roof decks and roof coverings shall be designed for wind loads in accordance with Chapter 16 and Sections 1504.2, 1504.3 and 1504.4.
- 2006 IBC prohibits of the use of aggregate used as surfacing on built-up roofs, and gravel and stone ballast on roofs in hurricane-prone regions (Hawaii)

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1504.1 Wind resistance of roofs.
Roof decks and roof coverings shall be designed for wind loads in accordance with Chapter 16 and Sections 1504.2, 1504.3 and 1504.4.

1504.2 Wind resistance of clay and concrete tile. Clay and concrete tile roof coverings shall be connected to the roof deck in accordance with Chapter 16.

1504.3 Wind resistance of nonballasted roofs. Roof coverings installed on roofs in accordance with Section 1507 that are mechanically attached or adhered to the roof deck shall be designed to resist the design wind load pressures for cladding in Chapter 16.

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Aggregate-Surfaced or Ballasted roofs are Prohibited by the 2006 IBC

The 2006 IBC prohibits of the use of aggregate (used as surfacing on built-up roofs), and gravel and stone (used as ballast on single-ply membrane roofing systems) on roofs in hurricane prone regions (HPR), and on taller buildings outside the HPR:

> **1504.8 Gravel and stone. Gravel or stone shall not be used** on the roof of a building located in a hurricane-prone region as defined in Section 1609.2, or on any other building with a mean roof height exceeding that permitted by Table 1504.8 based on the exposure category and basic wind speed at the building site.

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Wind and Debris Resistance of Garage Doors

- Garage doors are required to be tested for uniform static air-pressure resistance in accordance with ANSI/DASMA 108 or ASTM E330. The standards require that doors are tested for a minimum of 10 seconds to a pressure (referred to as test pressure) equal to 1.5 times the rated design pressure for the door.
  - American National Standard ANSI/DASMA 108-2012 (Uniform Static Air Pressure Difference)
- Windbrone Debris is tested on garage doors per ANSI/DASMA 115-2005 (Missile Impact and Cyclic Wind Pressure).

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Glazing Replacement for Maintenance

- The State Building Code does not require that replacement windows comply with windborne debris protection
- Section 3405.1 of Chapter 34 Existing Structures was amended to state:
- "The installation or replacement of glass shall be as required *by Chapter 24* for new installations."
- Chapter 24 does not include any requirements for windborne debris protection. The intent of the State amendment was to clarify that Section 3405.1 shall only require conformance to Chapter 24 and nothing further. That's why the Hawaii amendment to the IBC 2006 was created, to preclude over-reaching on the interpretation of this section.
- Making one window impact resistant in an existing building where no other window is impact resistant doesn't result in any real benefit of protection for the expense.
- Renovation to upgrade window systems is another matter.

End of this module

- Questions
  - The Effective Velocity maps are NOT WIND ZONES; they show wind speed contours
  - The effective wind speed contours on the maps are to be interpolated
  - Windspeed on the coastline is the nearest mapped contour inland if no offshore contour is given for interpolation
  - Broken glazing? Just replace the glazing if it was unprotected, it doesn't need to become windborne debris impact resistant glazing to meet the code.

HRS Chapter 107, Part II, State Building Code and Design Standards

IRC Use Limitations

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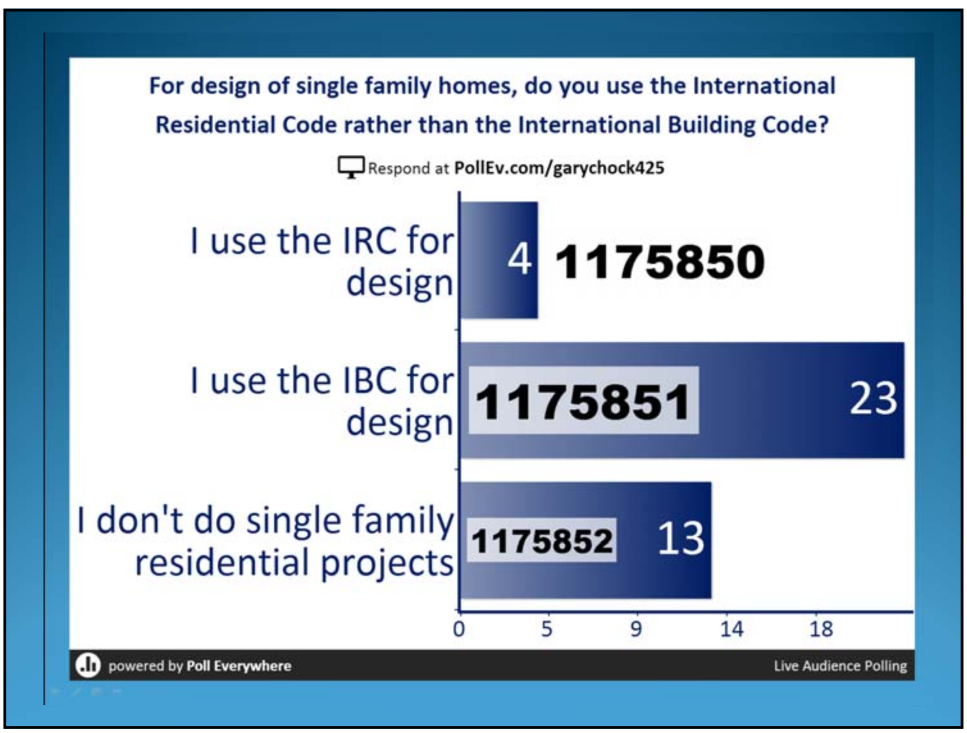

International Residential Code

- The IRC is essentially a pre-engineered wood-frame construction requirements for use where windspeeds are less than 100 mph and low to moderate seismic.
- A house designed following IRC Prescriptive Design (which has no allowance for internal pressurization) is weaker than an IBC design and would potentially fail so protected openings or a safe room is required.

  "Occupancy R-3 Buildings (including their components and cladding) designed as a partially enclosed structure in accordance with the International Building Code and with a residential safe room in accordance with Section R325."

International Residential Code Wind and Seismic Limitations

- **"R301.2.1 Wind limitations.** Buildings and portions thereof shall be limited by wind speed and construction methods in accordance with Table R301.2(1), <u>Figure R301.2(8),</u> and this code. <u>Wherever the basic wind speed is used for determination of the wind loads, the value shall be the Effective Basic Wind Speed, V_{eff}, determined from Figure R301.2(9), which adjusts the basic wind speed for special topographic wind regions."</u>
- "R301.2.2 Seismic provisions. The seismic provisions of this code shall apply to buildings constructed in Seismic Design Categories C, D0, D1 and D2, as determined in accordance with this section. Buildings in Seismic Design Category E shall be designed in accordance with the International Building Code, except when the seismic design category is reclassified to a lower seismic design category in accordance with Section R301.2.2.1."

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International Residential Code Seismic Limitations

- "R301.2.2.2 Seismic limitations. The following limitations apply to buildings in all Seismic Design Categories regulated by the seismic provisions of this code.

  R301.2.2.2.1 Weights of materials. Average dead loads shall not exceed 15 pounds per square foot (720 Pa) for the combined roof and ceiling assemblies (on a horizontal projection) or 10 pounds per square foot (480 Pa) for floor assemblies, except as further limited by Section R301.2.2."

- "R301.2.2.2.2 Irregular buildings. Prescriptive construction as regulated by this code shall not be used for irregular structures located in Seismic Design Categories C, D0, D1 and D."

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"R301.2.1.1 Design criteria. Construction in regions where the *effective wind speed,* V_{eff}*, from Figure Figure R301.2(9),* equal or exceed 100 miles per hour (45 m/s) shall be designed in accordance with one of the following:

1. American Forest and Paper Association (AF&PA) Wood Frame Construction Manual for One- and Two-Family Dwellings (WFCM) for enclosed buildings; or
2. Southern Building Code Congress International Standard for Hurricane Resistant Residential Construction (SSTD 10); or
3. **Minimum Design Loads for Buildings and Other Structures (ASCE-7);** or
4. American Iron and Steel Institute (AISI), Standard for Cold-Formed Steel Framing-Prescriptive Method for One- and Two-family Dwellings (COFS/PM) with Supplement to Standard for Cold-Formed Steel Framing – Prescriptive Method for One- and Two-Family Dwellings, for enclosed buildings.
5. Concrete construction shall be designed in accordance with the provisions of this code."

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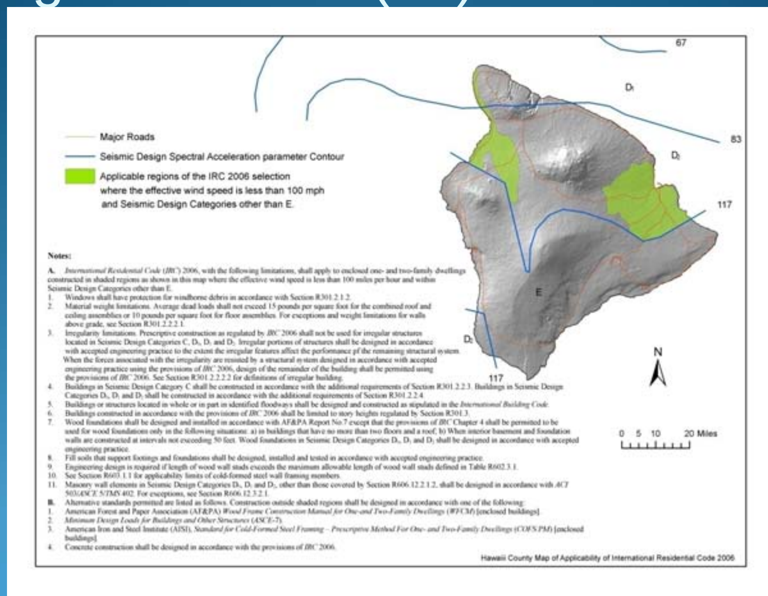
Figure R301.2 (8a)



Martin & Chock, Inc.

Figure R301.2 (8b)

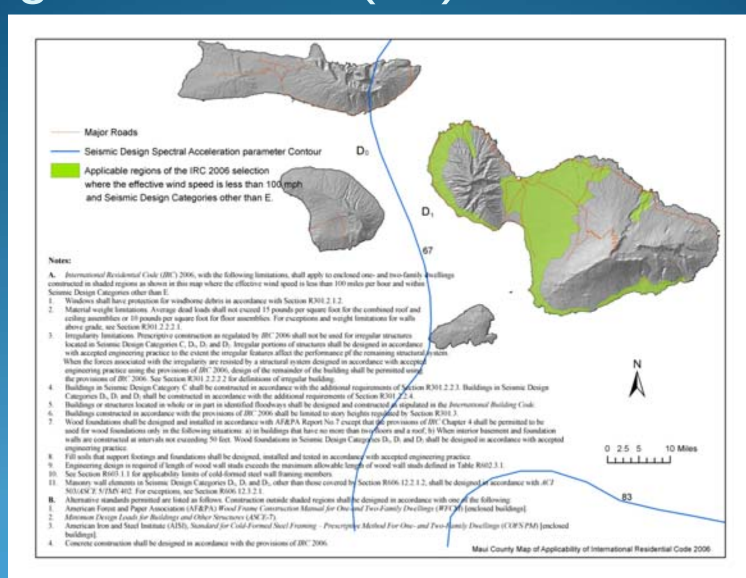


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Figure R301.2 (8c)

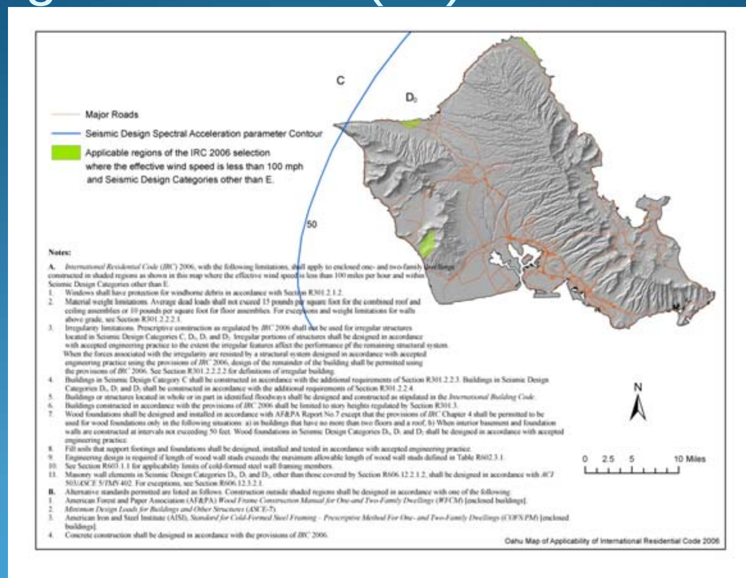

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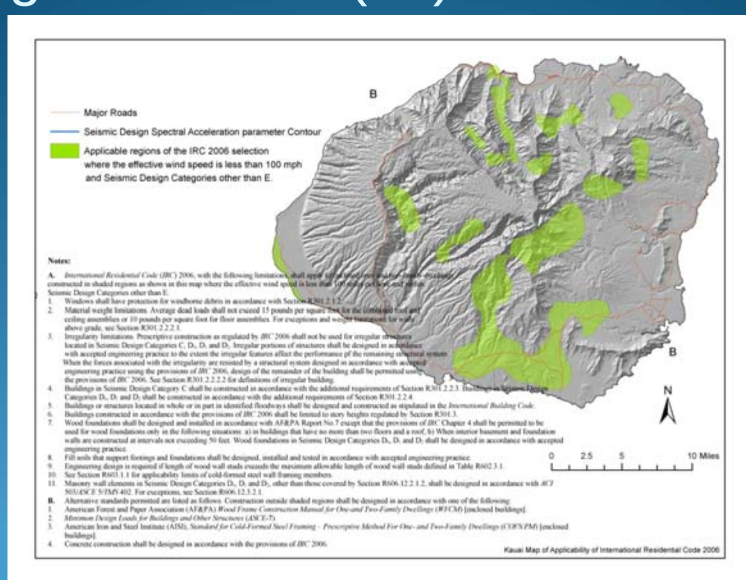
Figure R301.2 (8d)



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IRC Protection of Openings

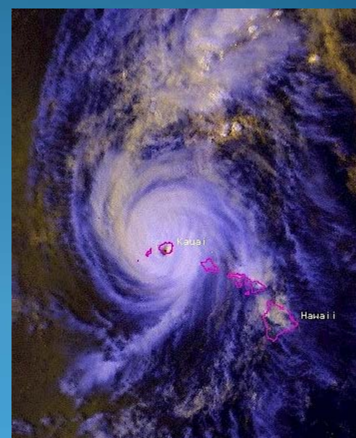
- If used, plywood panels for protection:
  - Shall be precut and predrilled
  - Permanent corrosion-resistant attachment hardware provided
  - Anchors shall be permanentely installed on the buildling
- Protection of openings not required if the building is designed as a partially enclosed structure per IBC requirments and has a residential safe room.

End of Module

- Questions?

The State Building Code

Upcoming Definition of Wind Loads on Residential Rooftop PV panels



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The Question from the Building Officials was: What Wind Pressures apply to Residential PV Panels Installed as Component Equipment on the Roof?

ARCHITECTURAL	EQUIPMENT
•Façades and Cladding Systems •Roofing •Parapets •Chimneys •Glass windows •Attachments (signs, antennae,etc) •Ornaments •Canopies •Doors	•Rooftop and Site equipment •Air conditioning •Electrical generator •Communicatons •Power

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There are many PV Panel Installations

- HRS Chapter 196 Section 6.5, part of the Hawaii Clean Energy Initiative, requires that on or after January 1, 2010, no building permit shall be issued for a new single-family dwelling that does not include a solar water heater system. Significant numbers of solar panels are being installed on other types of commercial and institutional buildings as well. Wind loads on roof-mounted solar panels are not specifically addressed in the current International Building Code.
- To resolve this ambiguity in order to mitigate against property damage due to solar panel windborne debris, the Structural Engineers Association of Hawaii has developed conservative load provisions generically based on wind-tunnel studies in collaboration with the author of the cited reference who has conducted numerous studies of rooftop solar panel systems over the past decade.

Two Parts to Wind Design: Structural and Nonstructural

First, the Main Wind Force Resisting System, or MWFRS is designed to structural integrity. This includes the structural components like wall framing, floor and roof diaphragms, and shear walls —elements that transmit the wind forces acting on the structure of the building.

Second, the wind design must address Components and Cladding, or C&C, such as roof sheathing, roof covering, exterior siding, windows, doors, soffits, fascias, and chimneys. This is where an architect, supplier, or builder will (or should) consult design pressure tables and determine the requirements for different building elements, including the windows.

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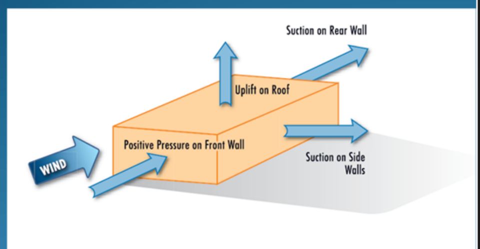
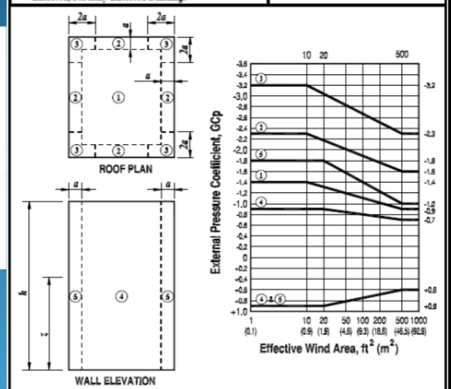
Designing the Envelope



- Example of C&C combined Gust - Pressure Coefficients for buildings taller than 60 ft.
- Note zones of higher pressure at corners or discontinuities
- *Coefficients vary with the size of element*

Components and Cladding		h > 60 ft.
Figure 30.6-1	External Pressure Coefficients, GCp	Walls & Roofs
Enclosed, Partially Enclosed Buildings		



Notes:
1. Vertical scale denotes GC_p to be used with appropriate q_z or q_h.
2. Horizontal scale denotes effective wind area A, in square feet (square meters).
3. Plus and minus signs signify pressures acting toward and away from the surfaces, respectively.
4. Use q_z with positive values of GC_p and q_h with negative values of GC_p.
5. Each component shall be designed for maximum positive and negative pressures.
6. Coefficients are for roofs with angle $\theta \le 10°$. For other roof angles and geometry, use GC_p values from Fig. 30.4-2A, B and C and attendant q_h based on exposure defined in Section 26.7.
7. If a parapet equal to or higher than 3 ft (0.9m) is provided around the perimeter of the roof with $\theta \le 10°$, Zone 3 shall be treated as Zone 2.
8. Notation:
   a: 10 percent of least horizontal dimension, but not less than 3 ft (0.9 m).
   h: Mean roof height, in feet (meters), except that eave height shall be used for $\theta \le 10°$.
   z: height above ground, in feet (meters).
   θ: Angle of plane of roof from horizontal, in degrees.

1609.5.4 Roof-Mounted Panels for Buildings with mean roof height up to 60 ft (18.3 m)

The design wind force for roof-mounted panels located on buildings with a mean roof height h less than or equal to 60 ft (18.3 m)) shall be permitted to be determined based on the location and height of the panel system and the configuration of the roof, in accordance with this section.

1609.5.4.1 Loads on panels mounted flush or within 6 inches of the roof surface and not located on a roof overhang nor in roof Zones 2 or 3. The normal force on panels mounted flush or within 6 inches of the roof surface and not located on a roof overhang nor in roof Zones 2 or 3 shall be determined using the Components and Cladding external pressure for the corresponding location on the roof, multiplied by the total area of an individual panel element, by the following equation:

- $F = q_h(GC_p)A$ (lb) (N) (1609.5.4.1-1)

1609.5.4 Roof-Mounted Panels for Buildings with mean roof height up to 60 ft (18.3 m)

GC_p shall be taken as the component and cladding external pressure coefficient for roofs for the roof zone corresponding to the location of the solar panel, and the effective wind area shall be that of the solar panel. The minimum magnitude of negative pressure values of GC_p in Zone 1 shall be taken as -1.0.

A shall be the total area of the solar panel element

Alternatively, it shall be permitted to determine the normal force by equation 1609.5.4.1-2:

$$F = 40\,A\,(Veff/105)^2 \quad \text{(lbs)} \qquad (1609.5.4.1\text{-}2)$$

Where

V_{eff} is the Effective Basic Wind Speed, Veff , determined from Figure 1609.1.1.1, which adjusts the basic Hawaii wind speed for the special topographic wind region.

The force F shall be permitted to be applied to the centroid of the calculated pressure.

1609.5.4 Roof-Mounted Panels for Buildings with mean roof height up to 60 ft (18.3 m)

- **1609.5.4.1.1 Non-additive panel and roof component and cladding loads.** The load on the panel located in accordance with Section 1609.5.4.1.1 need not be added to the resultant of the pressure acting on the portion of the roof underlying the panel. The roof shall be subject to Component and Cladding wind loads assuming that the roof-mounted panels are absent.
- **1609.5.4.2 Loads on all other panel locations.** The normal force on all other panel locations and configurations shall be determined by the following equation:
  - $F = q_h(GC_p)C_N A$ (lb) (N) (1609.5.4.2-1)
- where
  - C_N = pressure coefficients for monoslope free roofs from ASCE 7 considering each elevated panel as a free roof surface in clear wind flow. The angle θ used for the determination of C_N shall be measured as the angle of the panel with respect to the plane of the roof. Values of C_N for forces on the panel may be taken as the Zone 1 coefficients, except Zone 2 coefficients for C_N shall be used where panels of angle $\theta > 7.5°$ are located within *2h (2 x roof height) of a roof corner with a parapet taller than 24 inches.*
  - GC_p shall be taken as the component and cladding external pressure coefficient for roofs for the roof zone corresponding to the location of the solar panel, and the effective wind area shall be that of the solar panel. The minimum magnitude of negative pressure values of GC_p in Zone 1 shall be taken as -1.0.

1609.5.4 Roof-Mounted Panels for Buildings with mean roof height up to 60 ft (18.3 m)

1609.5.4.1.1 Non-additive panel and roof component and cladding loads. The load on the panel located in accordance with Section 1609.5.4.1.1 need not be added to the resultant of the pressure acting on the portion of the roof underlying the panel. The roof shall be subject to Component and Cladding wind loads assuming that the roof-mounted panels are absent.

1609.5.4 Roof-Mounted Panels for Buildings with mean roof height up to 60 ft (18.3 m)

1609.5.4.2 Loads on all other panel locations. The normal force on all other panel locations and configurations shall be determined by the following equation:

$$F = q_h (GC_p) C_N A \quad \text{(lb) (N)} \qquad (1609.5.4.2\text{-}1)$$

where

C_N = pressure coefficients for monoslope free roofs from ASCE 7 considering each elevated panel as a free roof surface in clear wind flow. The angle θ used for the determination of C_N shall be measured as the angle of the panel with respect to the plane of the roof. Values of C_N for forces on the panel may be taken as the Zone 1 coefficients, except Zone 2 coefficients for C_N shall be used where panels of angle θ > 7.5° are located within *2h (2 x roof height) of a roof corner with a parapet taller than 24 inches.*

GC_p shall be taken as the component and cladding external pressure coefficient for roofs for the roof zone corresponding to the location of the solar panel, and the effective wind area shall be that of the solar panel. The minimum magnitude of negative pressure values of GC_p in Zone 1 shall be taken as -1.0.

A shall be the total area of the solar panel element

1609.5.4 Roof-Mounted Panels for Buildings with mean roof height up to 60 ft (18.3 m)

1609.5.4.2 Loads on all other panel locations.
Alternatively, it shall be permitted to determine the normal force by equation 1609.5.4.2-2:

$$F = 100\,A\,(V_{eff}/105)^2 \text{ (lbs)} \qquad (1609.5.4.2\text{-}2)$$

where
V_{eff} is the Effective Basic Wind Speed, Veff , determined from Figure 1609.1.1.1, which adjusts the basic Hawaii wind speed for the special topographic wind region.

When located in roof zone 2 or 3 as defined in ASCE 7, the force F shall be applied with an eccentricity equal to a third of the solar panel width.

1609.5.4.2.1 Additive panel and roof component and cladding loads The load on the panel shall be applied as point load anchorage reactions additive to the resultant of the pressure determined acting on the portion of the roof underlying the panel.

1609.5.4 Roof-Mounted Panels for Buildings with mean roof height up to 60 ft (18.3 m)

1609.5.4.3 Permeability. No reduction of load on the panels shall be taken for permeability of the panel system unless demonstrated by approved wind-tunnel testing or recognized literature for the type of panel system being considered, replicating the panel separation spacing and height above the roof.

1609.5.4.4 Shielding. No reduction of load on the panels shall be taken for shielding provided by the roof, or given by obstruction to, the panel system unless demonstrated by approved wind-tunnel testing or recognized literature for the type of panel system being considered, replicating the panel separation spacing and height above the roof.

1609.5.4.5 Ballasted panels.

1609.5.4.5 Ballasted panels. Ballasted panel systems that are ballasted for anchorage purposes and that are tilted at an angle α of 10 degrees or more from a horizontal plane shall each be ballasted to resist a force determined by the following equation:

$$F_{ballast} \geq F\left(\frac{\mu \cos\beta + \sin\beta}{\mu \cos\alpha - \sin\alpha}\right) \quad \text{(lb) (N) (1609.5.4.5.1)}$$

where

F = the normal force on each panel determined by equations 1609.5.4.1-1 or 1609.5.4.2-1

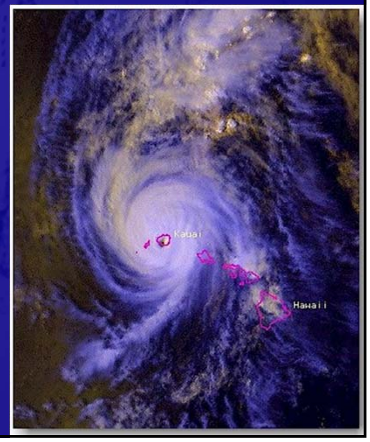
α = the angle of the roof plane with respect to horizontal

β = the angle of tilt of the panel with respect to the roof plane

μ = the static friction coefficient between the panel base and its bearing surface

Alternatively, To resist uplift and sliding, ballasted panel systems that are tilted at an angle of less than 10 degrees from a horizontal plane shall each be ballasted to resist a force equal to 2 times the normal force on each panel determined in Sections 1609.5.4.1 or 1609.5.4.2. Ballasted panels that are tilted at an angle between 10 degrees to 25 degrees from a horizontal plane shall each be ballasted to resist a force equal to 8 times the normal force on each panel determined in Sections 1609.5.4.1 or 1609.5.4.2

The Wind Load Provisions of ASCE 7 Updates Explained: The Update from 2005 to 2010 and the Hawaii Special Wind Region



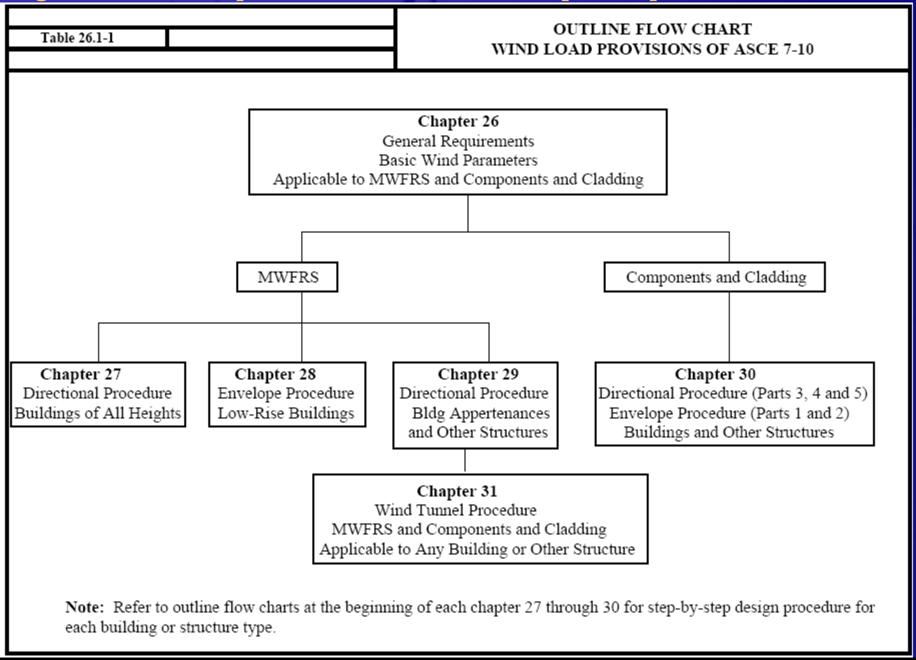
Gary Chock, P.E.

Member, ASCE 7 Wind Load Subcommittee
SEAOH Representative to the Hawaii State Building Code Council

Summary of Significant Changes in the ASCE 7 - 2010 Wind Design Provisions

- RE-ORGANIZATION OF THE WIND LOAD CHAPTER FOR CLARITY OF PRESENTATION of METHODS for MWFRS and C&C
- NEW WIND MAPS with Strength-Level Basis of Design
- EXPOSURE D in HURRICANE PRONE REGIONS
- WINDBORNE DEBRIS CRITERIA RECALIBRATED
- WIND –TUNNEL PROCEDURE LIMITATIONS

Re-organization of Chapter 6 Wind Load into Multiple Chapters in ASCE 7-2010



Clarifying the Parts of Wind Design: MWFRS and C&C

- **MAIN WIND-FORCE RESISTING SYSTEM:** Can consist of a structural frame or an assemblage of structural elements that work together to transfer wind loads acting on the entire structure to the ground. Structural elements such as cross-bracing, shear walls, roof trusses, and roof diaphragms are part of the Main Wind-Force Resisting System (MWFRS) when they assist in transferring overall loads.
- **COMPONENTS AND CLADDING:** Components receive wind loads directly or from cladding and transfer the load to the MWFRS. Cladding receives wind loads directly. Examples of components include fasteners, purlins, girts, studs, roof decking, and roof trusses. Components can be part of the MWFRS when they act as shear walls or roof diaphragms, but they may also be loaded as individual components.

Hurricane Hazard from an Engineering Perspective of Risk

CONCEPTS

- Safety Goal: The fundamental goal of an engineered design is to provide sufficient resistance to hazards so that the probability of exceeding the design capacity are kept to acceptably low odds of failure over the lifetime of the facility.
- Reliability is the quantified probability of not violating the capacity of the system
- Building codes for structural design provide procedures for attaining the desired target reliability that meets the safety goal.
- The estimated annual odds of reaching or exceeding a hazard level (such as wind speed) are often described by the return period, which is by definition: 1/(annual odds of experiencing or exceeding the hazard level)

Design Wind Velocities based on Reliability

- Peak Gust wind velocity is the primary determinant of the design wind forces on a building.
- Design wind velocity is determined by:
  - The importance of the building
  - The typical "economic" lifespan of the building
  - The chances of a certain peak gust wind velocity occurring during that lifespan.
  - The structural capacity against wind forces

Reliability Example Exercise using Basic Probability or Gaming Theory

- Question: What are the chances of overloading a building *designed to a 100-year return period* over an economic lifespan of 50 years?
- To have no overload you must have 50 successful years when the annual odds of a failure is 1/100 or 1%. The chance of one successful year is 99%. The chance of no overload at all over 50 years is then $(0.99)^{50}$ = 60.5%
- **The chances of overloading (failing) the structure during its lifespan would therefore be 100% - 60.5% = 39.5%**
- Therefore, a structure designed for only a 100-year return period would have a very high probability of failure. Not a good reliability at all, with only a 60.5% chance of avoiding an overload!

Targeted Windspeed

- Most buildings have an economic lifespan of at least 50 years, and the reliability objective of engineering is to have only a small chance of failure during that entire time
- **The return period for design is selected to limit the chances of exceeding the design windspeed to 3% to 7% over 50 years**

7% to 3% over 50 yrs

Chance in % of winds exceeding design over a lifespan

RETURN PERIOD YEARS	2	5	10	20	50	100	200	500	1000	2000	5000	10000
ANY 1 YEAR	50 40 30 25	20 15	10	5	2	1	0.5	0.2	0.1	0.05	0.02	0.01
TEN YEAR S		80	65	40	18	9.5	5	2	1	0.5	0.2	0.1
TWENTY FIVE YEARS		99	94	71	40	22	12	5	2.5	1.2	0.5	0.25
FIFTY YEARS			99.9	90.5	61	39	22	9.5	4.8	2.3	1.0	0.5
ONE HUNDRED YEARS					86	64	40	18	10	5	2	1

Building Code Design Wind Velocities

In codes, buildings are classified according to the level of risk that society can tolerate.

IBC CATEGORIES OF BUILDING RISK

- I **Buildings that represent a low hazard to human life in the event of failure**. (e.g., a low occupancy agricultural warehouse).
- II **Buildings except those listed in Categories I, III and IV** (e.g., a commercial building)
- III **Buildings that represent a substantial hazard to human life in the event of failure** (e.g., a school)
- IV **Buildings designated as essential facilities** (e.g., a hospital)

From IBC TABLE 1604.5.

Building Code Design Wind Velocities

The building Risk Category determines the mean return period for the wind hazard (steel and concrete structures)

From ASCE 7-2010

Risk Category	Description	Mean Return Period	Probability of windspeed exceedance in a 50 year lifespan
I	Agricultural, Temporary, and Storage Facilities with low occupancy	300 (0.33%/yr)	85%
II	"Normal Occupancies"	700 (0.14%/yr)	93%
III and IV	High Hazard Occupancies (such as assembly, Power, Telecom, Hazmat, Explosives,) and Essential Facilities	1700 (0.059%/yr)	97%

ASCE 7 2010 Determination of Design Wind Speeds at the Strength Level Basis of Design

- Incorporates a new probabilistic analysis with an improved windfield model for the continental U.S.
  - More data
  - More refined hurricane windfield model
  - Analysis reflects a higher frequency of storms but less intense compared to the past model
- Perform the load calculation at the strength design point
  - LRFD design
  - Wind maps at 300-1700 year recurrence depending on occupancy category
  - Load Factor = 1.0 (versus 1.6 today with various Importance Factors)
  - Other wind maps provided in the appendix at 10, 50, 100-years etc. for serviceability and drift checks
  - Allowable Stress Load Combination is now defined by using 0.6 factor for wind
- Design wind speed return period is based on occupancy, and the Importance Factor is thus eliminated

Reasons

- New data and research indicates that the current hurricane wind speeds given in ASCE 7 were conservative in the continental USA and needed to be adjusted downward.
- A strength design wind speed map is more aligned with seismic design in that they both use a load factor of 1.0 for strength design.
- Multiple maps eliminate the problem of having importance factors that vary with occupancy category and hurricane prone and non-hurricane prone regions.
- The use of multiple maps eliminates the confusion of engineers not understanding that the present wind map is not a 50-year return period map.
- Engineers have not understood that their design, after multiplication by the 1.6 load factor, was a roughly 700 year event with wind speeds $\sqrt{1.6}$ times that shown on the map.
- Building owners have not understood that their buildings would not fail for wind speeds somewhat above the present map value. The revised maps give the owner a better idea of the wind speeds for which the onset of significant damage is expected in an engineered structure.

Expected Strengths of modern ASCE 7-Designed Structures

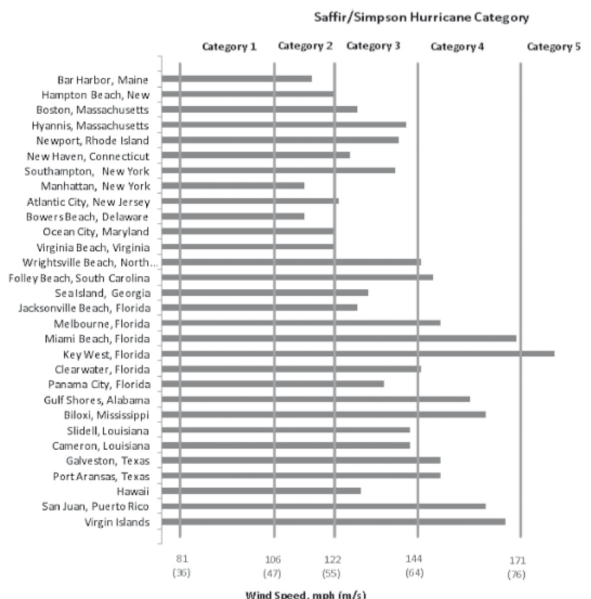
- Recalibration Table

TABLE C26.5-6 Design Wind Speeds: ASCE 7-93 to ASCE 7-10

ASCE 7-05 Design Wind Speed (3-sec gust in mph)	ASCE 7-10 Design Wind Speed (3-sec gust in mph)	ASCE 7-93 Design Wind Speed (fastest mile in mph)
85	110*	71
90	115*	76
100	126	85
105	133	90
110	139	95
120	152	104
130	164	114
140	177	123
145	183	128
150	190	133
170	215	152

*Wind speed values of 110 mph and 115 mph were rounded from the "exact" conversions of $85\sqrt{1.6} = 108$ and $90\sqrt{1.6} = 114$ mph, respectively.

Table C26.5-4 Basic Wind Speed for Risk Category II Buildings and Other Structures at Selected Locations in Hurricane Prone Areas



PART I Enclosed and Partially Enclosed Buildings of All Heights

General Requirements – Velocity Pressure

The ASCE/SEI Standard 7-10 utilizes the following equation for velocity pressure:

$$q = 0.00256\ K_z\ K_{zt}\ K_d\ V^2$$

where:

K_z is the velocity pressure exposure coefficient that is defined according to system or component design cases and terrain category,

K_{zt} is the topographic speed-up factor,

K_d is the wind directionality factor which accounts for the fact that the probability that the maximum wind may not impact the structural component or system in its weakest orientation,

V is the peak gust windspeed associated with a the return period specified for the Occupancy

The difference is that ASCE 7-10 uses the strength-based V based on Occupancy and thus has eliminated the Importance Factor

Basic Wind Speed Maps, V

Occupancy Category	Description	Map Return Period
I (ASCE 7 -10)	Agricultural, Temporary, and Minor Storage	300
II (ASCE 7 -10)	“Normal Occupancies”	700
III and IV (ASCE 7 -10)	High Hazard Occupancies (such as assembly, school buildings with > 250 occupants, Power, Telecom, Hazmat, Explosives,) and Essential Facilities	1700
I (ASCE 7- 05)	*V * √1.6 * √0.77 gives the LRFD equivalent in the present standard*	
II (ASCE 7-05)	*V * √1.6 gives the LRFD equivalent in the present standard*	
III and IV (ASCE 7-05)	*V * √1.6 * √1.15 gives the LRFD equivalent in the present standard*	

The ASCE 7 Commentary provides the conversion from ASCE 7-05 design wind speeds, for use in allowable stress design-based product evaluation reports and test methods, to the equivalent strength design-based design wind speeds now used in the ASCE 7-10

$$\sqrt{1.6}\, V_{7\text{-}05} = V_{7\text{-}10}$$

ASCE 7-05 ASD Design Wind Speed	ASCE 7-10 LRFD Design Wind Speed	ASCE 7-93 ASD FM Design Wind Speed
85 mph	**110 mph**	71 mph
90 mph	**115 mph**	76 mph
100 mph	**126 mph**	85 mph
105 mph	**133 mph**	90 mph
110 mph	**139 mph**	95 mph
120 mph	**152 mph**	104 mph
130 mph	**164 mph**	114 mph
140 mph	**177 mph**	123 mph
145 mph	**183 mph**	128 mph
150 mph	**190 mph**	133 mph
170 mph	**215 mph**	152 mph

IBC also provides a conversion table from ASCE 7-10 wind speeds to ASCE 7-05 equivalent wind speeds and an algebraic formulation of the conversion

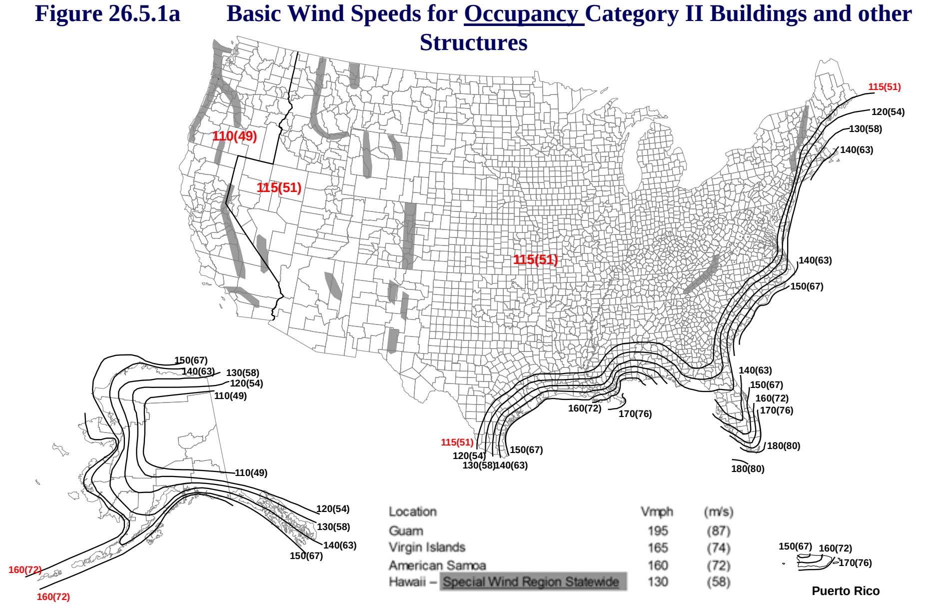
Hurricane Prone Regions Definition Recalibrated to the Strength Level Windspeed

HURRICANE PRONE REGIONS: Areas vulnerable to hurricanes; in the United States and its territories defined as

1. The U.S. Atlantic Ocean and Gulf of Mexico coasts where the basic wind speed for Category II buildings is greater than ~~90~~ 115 mi/h, and
2. Hawaii, Puerto Rico, Guam, Virgin Islands, and American Samoa.

- Reasoning: Adjusted the wind speed criteria by √1.6 to the Strength level used with a LF of 1.0
- Wind speed criteria boundary only applies to the continent to account for inland intensity degradation after hurricane landfall

Figure 26.5.1a Basic Wind Speeds for Occupancy Category II Buildings and other Structures



Notes:
1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10m) above ground for Exposure C category.
2. Linear interpolation between contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 7% probability of exceedance in 50 years.

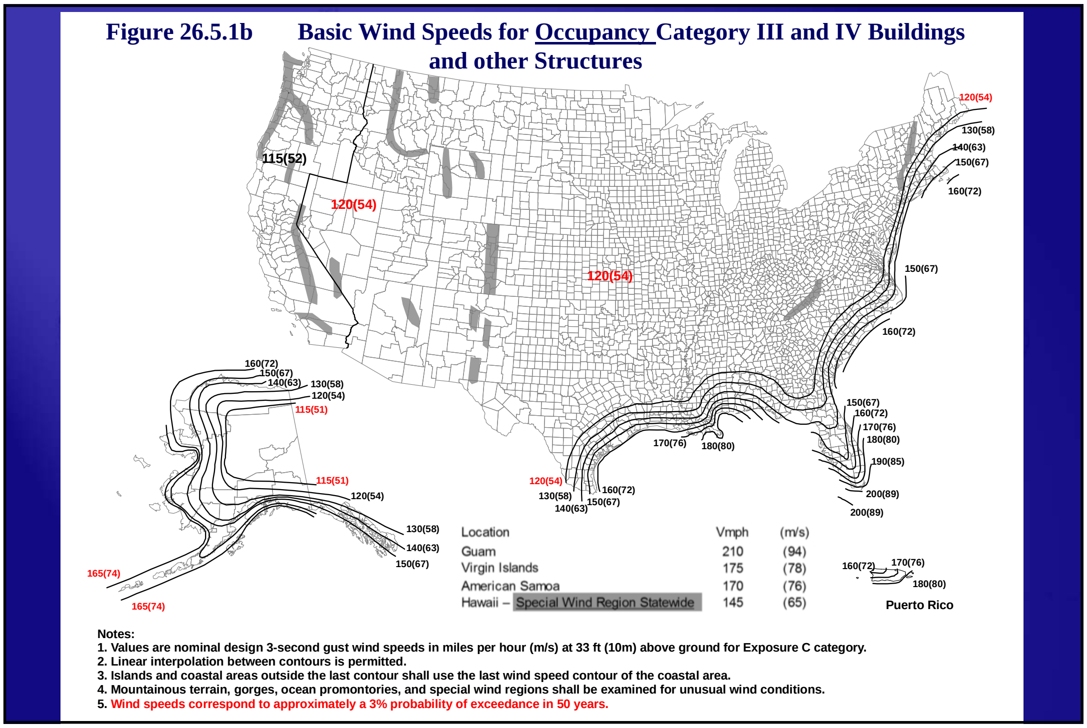
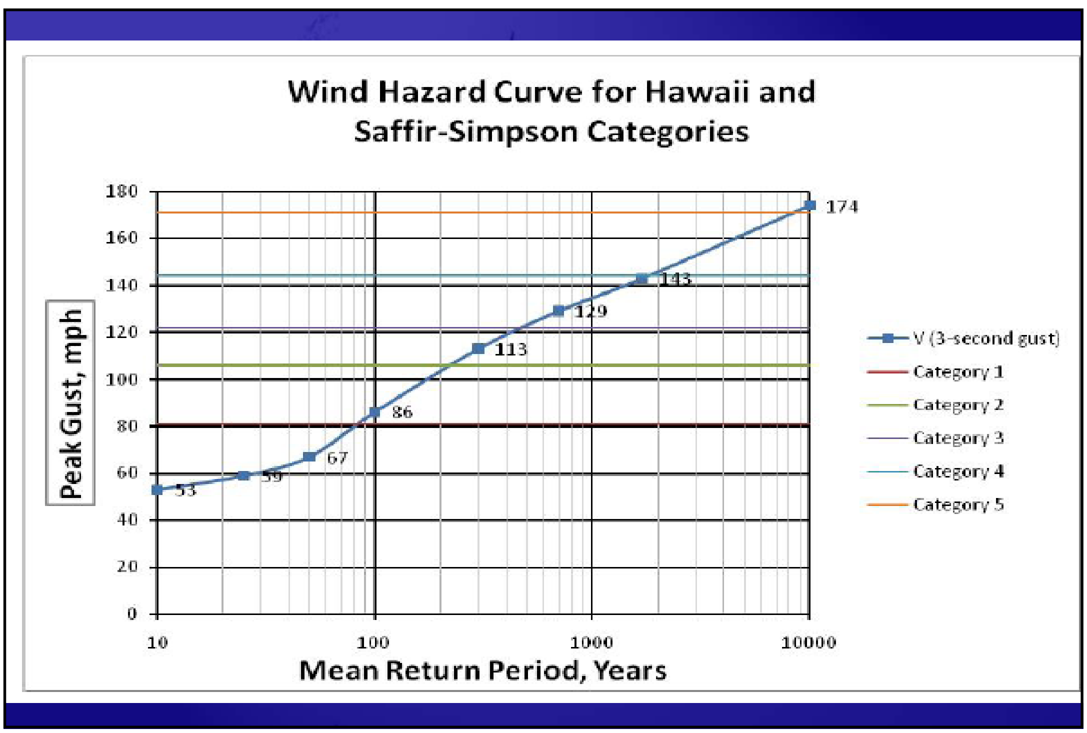


Figure 26.5.1b Basic Wind Speeds for Occupancy Category III and IV Buildings and other Structures
115(52)
120(54)
130(58)
140(63)
150(67)
160(72)
170(76)
180(80)
190(85)
200(89)
115(51)
165(74)
Location | Vmph | (m/s)
Guam | 210 | (94)
Virgin Islands | 175 | (78)
American Samoa | 170 | (76)
Hawaii – Special Wind Region Statewide | 145 | (65)
Puerto Rico
Notes:
1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10m) above ground for Exposure C category.
2. Linear interpolation between contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 3% probability of exceedance in 50 years.


Wind Hazard Curve for Hawaii and Saffir-Simpson Categories
Peak Gust, mph
0
20
40
60
80
100
120
140
160
180
10
100
1000
10000
Mean Return Period, Years
53
59
67
86
113
129
143
174
V (3-second gust)
Category 1
Category 2
Category 3
Category 4
Category 5

Use of Effective Velocity, V_{eff}

- In areas of topographic speed-up, this new velocity term is defined in order to provide a nearly uniform level of protection for hurricane hazard, regardless of whether the designer uses the IBC, Simplified ASCE, or the International Residential Code (IRC), WFCM, etc.

$$q = 0.00256\ Kz\ Kzt\ Kd\ V^2$$

$$V_{eff} = V * \sqrt{(Kzt \times Kd / 0.85)}$$

$$q = 0.00256\ Kz\ Veff^2$$

- Consequently, the designer may simply use a map of V_{eff} and the map of Exposure Category. The maps of V_{eff} are also used to determine the correct wind zone for ASTM E1996 Windborne Debris

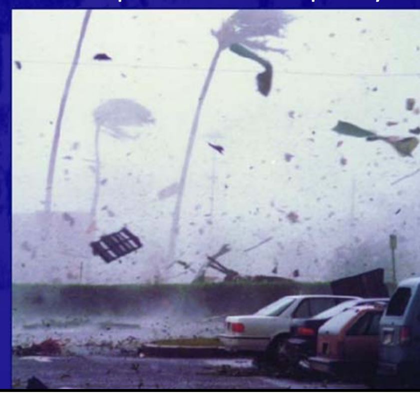
Martin & Chock, Inc.

Exposure D in Hurricane Prone Regions Updated based on NOAA NWS Research

- Research since 2004 has showed that the drag coefficient over the ocean in high winds in hurricanes did not continue to increase with increasing wind speed as previously believed. The studies showed that the sea surface drag coefficient, and hence the aerodynamic roughness of the ocean, reached a maximum at mean wind speeds of about 30 m/sec (~70 mph peak gust). There is some evidence that the drag coefficient actually decreases (i.e. the sea surface becomes aerodynamically smoother) as the wind speed increase further, or as the hurricane radius decreases. The consequences of these studies are that the surface roughness over the ocean in a hurricane is more consistent with that of exposure D rather than exposure C. Consequently, the use of exposure D *along* the hurricane coastline 600 ft inland is now required under ASCE 7-10.

Windborne Debris Regions Recalibrated, to Vary by Structural Occupancy

- The introduction of separate risk based maps for different occupancy categories provides a means for achieving a more risk consistent approach for defining windborne debris regions. The approach selected was to link the geographical definition of the windborne debris regions to the wind speed contours in the maps that correspond to the particular occupancy category.



Windborne Debris Regions to Vary by Structural Occupancy

WIND-BORNE DEBRIS REGIONS: Areas within hurricane prone regions located:

1. Within 1 mile of the coastal mean high water line where the basic wind speed, for the building category under consideration, is equal to or greater than 130~~110~~ mi/h

or

2. In areas where the basic wind speed, for the building category under consideration, is equal to or greater than 140~~120~~ mi/h.

Reasoning: adjusted the windspeed to the LRFD design level with a LF of 1.0 instead of 1.6, and reference the new strength-level wind maps of return periods that are occupancy category dependent

IBC 1609.1.2.2. Application of ASTM E 1996

Section 6.2.2 of ASTM E 1996 shall be substituted as follows: Unless otherwise specified, select the wind zone based on the strength design wind speed, *V*:

Wind Zone 1—130 mph ≤ V < 140 mph.

Wind Zone 2—140 mph ≤ V < 150 mph at greater than one mile (1.6 km) from the coastline.

Wind Zone 3—150 mph (58 m/s) ≤ V ≤ 160 mph (63 m/s), or

140 mph (54 m/s) ≤ V ≤ 160 mph (63 m/s) and within one mile(1.6 km) of the coastline. The coastline shall be measured from the mean high water mark.

Wind Zone 4 — V >160 mph (63 m/s).

For Hawaii, we will have updated V_{eff} *maps for each Risk Category*

Wind Tunnel Procedure

- **WIND TUNNEL PROCEDURE:**
  A procedure for determining wind loads on buildings and other structures, in which pressures and/or forces and moments are determined for each wind direction considered, from a model of the building or other structure and its surroundings, in accordance with Chapter 31.

31.4.3 Limitations on Loads (from Wind-Tunnel)

The limiting values of 80 percent may be reduced to 50 percent for the main wind force resisting system and 65 percent for components and cladding if either of the following conditions applies:

1. There were no specific influential buildings or objects within the detailed proximity model.
2. Loads and pressures from supplemental tests for all significant wind directions in which specific influential buildings or objects are replaced by the roughness representative of the adjacent roughness condition, but not rougher than exposure B, are included in the test results.

Summary

- IBC 2012 utilizes the ASCE 7-2010 Standard.
- Wind maps of Basic Wind Speed have been produced at the strength level for each Structural Occupancy.
- Hurricane Prone Region and Windborne Debris Criteria have been recalibrated.
- The use of wind-tunnel study results have been clarified.
- Hawaii is a special wind region with
  - Topographic Factor Maps (unchanged)
  - Tables of Directionality Factor (unchanged)
  - Effective Wind Speed for Cladding and Components and Windborne Debris (to be revised)
  - Exposure Maps based on satellite imagery of land-cover data and wind profile test data (maybe revised)

End of Module and Workshop

- Hawaii is lagging behind the times compared to the west coast state codes.
- Engineers can use the ASCE 7-10 Standard in Hawaii if they apply the Hawaii Topographic Factor, Hawaii Directionality Factor, and use the Hawaii Exposure Maps with exposure D along the coastline 600 ft inland for onshore winds. The windborne debris requirements would need to follow the Hawaii State Building Code amendments to the IBC 2006 and ASCE 7-05 Standard.
- Windborne Debris requirements for Hawaii in the 2012 IBC and ASCE 7-10 Standard will require the use of the next generation of Hawaii Effective Windspeed maps for each Risk Category of structure. FEMA was supposed to release grant funding for these new maps.