SUMMARY OF UF 2004 HURRICANES BUILDING PERFORMANCE ASSESSMENT AND ARA WIND-BORNE DEBRIS CRITERIA FOR THE PANHANDLE STUDY

The question to be resolved by the Florida Building Commission is whether wind-borne debris is a significant risk for the Panhandle region of Florida and if so what regulatory (building code) criteria is appropriate to address that risk.

The 2005 Florida Legislature directed the Commission to consider the effects of Hurricane Ivan and other data to determine an appropriate designation of the zone within the Panhandle where wind borne debris protection would be required by the Florida Building Code. Current national standards assume that in areas where hurricane winds equal or exceed 120 mph (3 second gust), the amount and energy of wind borne debris becomes a significant risk to window and glass breakage, which in turn allows wind and rain into buildings resulting in dramatic increases in damage and lost use of the building. Hurricane Ivan was not a “design” storm (a storm with wind speeds at least equal to the speeds buildings must be designed to resist according to the Code) and did not have winds equaling or exceeding 120 mph with the possible exception of winds experienced on the barrier islands. Consequently, data collected by the University of Florida and ARA on Hurricane Charley, the only 2004 hurricane which had wind speeds exceeding 120 mph, and data from the ARA simulation study of the Panhandle region will be the basis of consideration.

The University of Florida (UF), Post 2004 Hurricane Field Survey Evaluation of the Relative Performance of the Standard Building Code study and the Florida Building Code and the Applied Research Associates (ARA), Wind-Borne Debris Criteria for the Florida Panhandle study provide the first extensive base of science for evaluation of wind borne debris protection for buildings built to improved wind resistance design standards developed after Hurricane Andrew in 1992. Standards established by the American Society of Civil Engineers prior to the 2004 hurricanes were a best guess consensus based on experience with older, weaker buildings. The findings of the UF post 2004 hurricane field surveys are conservative because they are based on information both for houses built between 1994 and 2001 to post-Hurricane Andrew standards (roughly two thirds of the sample in Hurricane Charley impacted Port Charlotte area) and houses built after 2002 to the Florida Building Code. The ARA simulation study is also conservative in many ways because subdivision model assumes mixed age buildings, a mix of single story and two story buildings and primarily subdivision perimeter shielding by trees. The effects of these conservative assumptions are counteracted by other assumptions as noted in the report including size of subdivision and perimeter tree buffers. Together, this new body of science gives a conservative picture of the impact of trees on shielding from hurricane force winds and the resultant reduction of wind borne debris.

Below are the questions that need to be addressed for the Commission to solve the problem before it, designation of the Wind Borne Debris Region for the Florida Panhandle and the data, conclusions and recommendations from the studies that will assist in your analysis and deliberations. The full reports will also be provided for further reference.

Question 1: What is the scope of the wind borne debris problem.

Hurricane Charley data:

The **University of Florida study** conducted a statistical sampling of homes built between 1994 to 2004 with roughly one third of those homes experiencing winds greater than 130 mph built to the 2001 Florida Building Code. The following information are an aggregate of all sampled homes.

The University of Florida assessment found 3-4 percent of unprotected windows were damaged requiring replacement with 1-2 percent reported as breached in areas where the wind speeds were in the range of 130-150 mph. (Figure 13, UF report, "Post 2004 Hurricane Field Survey…")
This translates to an overall 31 percent of houses surveyed, which includes pre-2001 Florida Building Code as well as houses built to the 2001 FBC, having at least one window damaged (not necessarily breached) in those wind zones. (Figure 14, UF report, "Post 2004 Hurricane Field Survey…")

The UF report also found, "The most significant observation is a lack of structural damage to any of the homes surveyed, even in the highest wind zones of Hurricane Charley." (p. 8, Observations: Summary of Findings, Structural Damage, UF report, "Post 2004 Hurricane Field Survey…")

An **ARA study** (FEMA sponsored) of the Hurricane Charley impacted area that surveyed 370 houses found 29 percent of houses with unprotected windows had at least one window damaged. (Slide 28, ARA Hurricane Charley Survey, ARA report, "Wind-borne Debirs Criteria for the Florida Panhandle)

Comment:
The studies indicate that structural failure due to breach of windows by wind borne debris and resulting building internal pressurization is not the problem in post 1993 houses it was in houses built to pre-1993 building codes.
However, breach of unprotected glazing does allow increased water damage and potentially "blow through" of hurricane force winds when internal pressurization results in leeward side opening blow-out thereby degrading the "safe shelter" value of a home.
Increased water damage has insurance and loss of use implications.
"Blow-through" has significant impacts on "shelter-in-place" strategies for emergency management.

Question 2: What is a reasonable and effective regulatory criteria.

ARA "Wind-Borne Debris Criteria for the Florida Panhandle" simulation study.

SUMMARY OF ARA SIMULATION STUDY CONCLUSIONS:

- Wind Borne Debris (WBD) is a dominant risk to buildings in **open** and **suburban** terrains.
- Failed openings lead to internal pressures in the building (increasing chance for further failures due to increased loads) and water penetration in the building>
- Trees dramatically reduce the loads on buildings and the low level windspeeds, thereby significantly reducing the WBD risk.
- Within the windspeed contours (110 to 130 mph 3 sec gust) investigated, **terrain is more important than windspeed** in determining the need for WBD protection.
- In medium treed terrain, the Benefit Cost ratios *for WBD protection* are generally much less than 1 *(not cost effective)*. Note: Ratios greater than 1 indicate more benefit than cost and ratios less than one indicate more costs than benefit.
- In light treed terrain, the results were mixed *(sometimes cost effective and sometimes not)* and dependent on the range of benefit cost parameters.
- In open-suburban terrain the lowest winds investigated (110 mph) produced average (of the six houses modeled) benefit/cost ratios greater than 1 *(cost effective).*
- The most beneficial solution for society is to implement a WBD criteria that considers both windspeed and terrain, much as the pressure load coefficients are terrain dependent.
- In light and medium tree terrains, tree fall risk on house seems to be higher than WBD risk. Cost-beneficial strengthening solutions should be investigated for tree fall protection.
- Openings should be protected in:
  - Open-suburban terrain
  - Suburban terrain in the range 110-130 mph, depending on cost assumptions
  - The results for light trees show reduced risk and benefit cost depends on cost assumptions

.Qualifiers on the study:

- Key research qualifications in the study results include:
  - Glass breakage by shingle missle
  - Shingle debris transport validation
  - Effects of tree blowdown on velocity profiles, loads
  - Effects of tree blowdown on losses (overestimates effectiveness of shutters)
  - Limited treed terrain test parameters
    - Investigate larger subdivisions
    - Investigate configurations with fewer trees
    - Investigate smaller tree buffers around subdivisions

ARA SIMULATION STUDY RECOMMENDATION:

Pursue a 2 stage approach to redefining the Wind Borne Debris Protection Region for the Panhandle and Florida.

Stage 1:	Immediate. Interim criteria should be implemented until second phase of study is completed.
Stage 2:	One year targeted completion. Conduct second phase of the study. Replaces interim designation of WBD region **statewide** when completed.

Stage 1 Criteria for Panhandle WBD region designation:
Adopt a 130 mph contour as the WBD region in the Panhandle. This option would also include all areas within 1500 feet of the inland Bays that are not within the 130 mph contour.
This is based on a reasonable balance of benefits and costs.

Stage 2 Rationale:
As stated in the conclusions of this study, the effect of trees on wind speeds and loads on buildings is so significant to Wind Borne Debris risk it should be included in the regulatory scheme applied by the Code. However, this effect is not unique to the Panhandle of Florida so the regulatory scheme should be fleshed out for application throughout the state. Also, the current data indicate that WBD protection can be cost effective in open and suburban with no tree terrains at wind speeds less than 20 mph.

Comment:

Other options include ignoring the research and:

- Retaining the current WBD region designation as the area within 1 mile of the coast, or
- Implementing the designation applied by the Code elsewhere in the state- i.e. areas where design wind speeds are 120 mph or greater.

The following excerpts from the study reporting are provided for quick reference. The complete report is provided separately for in-depth review.

Recommendations

- Windspeed and terrain dependent WBD criteria should be implemented in Florida and nationally
- Phase II should proceed to finalize terrain parameters for building code implementation.
- Such research would include more wind tunnel experiments, additional analysis of existing hurricane damage data, impact tests for shingles, and integration of land use criteria. Such research would take a year to complete, review, and develop suggested terrain and windspeed codification wording.
- Hence, we recommend a two-phased implementation approach:
  - Phase I: 2007 Panhandle Adjustment to Current Florida WBD Region
  - Phase II: 2008 Statewide Implementation of Windspeed/Terrain-Dependent WBD Criteria
- We note that the recent NIST report on Hurricane Katrina recommends:

  Evaluate the effects of shielded (e.g., wooded or wooded/suburban) exposures and their potential for reducing the wind loads on nearby residential structures and better explaining the variation in observed damage.

Conclusions

1. WBD is a dominant risk to buildings in open and suburban terrains.
   - Glazing WBD failure in Open Terrain have occurred in peak gust winds as low as 80 mph
   - In treed terrain, no glazing failures were noted in the UF survey for Hurricane Ivan in 100-110 mph
   - In Hurricane Charley, the ARA survey of over 300 houses indicated:
     - Similar % roof cover loss for shingles and tiles
     - 17-18% loss for old code, 8-9% for new code
     - Tile neighborhoods experienced 33% window breakage for unprotected openings
     - Shingle neighborhoods experience 24% window breakage for unprotected openings
   - In Hurricane Andrew, over 90% of houses in the NAHB survey experienced broken windows from WBD
2. Failed openings lead to internal pressures in the building (increasing chance for further failures due to increased loads) and water penetration in the building.
3. Trees dramatically reduce the loads on buildings and the low level windspeeds, thereby significantly reducing the WBD risk.

Conclusions (cont'd)

4. Within the windspeed contours (110 to 130mph) investigated, terrain is more important than windspeed in determining the need for WBD protection.
5. In medium treed terrain, the BC ratios are generally <<1.
6. In light treed terrain, the results were mixed and dependent on the range of benefit cost parameters.
7. **The most beneficial solution for society is to implement a WBD criteria that considers both windspeed and terrain, much as the pressure load coefficients are terrain dependent.**
8. In light and medium tree terrains, tree fall risk on house seems to be higher than WBD risk. Cost-beneficial strengthening solutions should be investigated for tree fall protection.

Conclusions (cont'd)

9. Key research qualifications in these results include:
   - Glass breakage by shingle missiles
   - Shingle debris transport validation
   - Effects of tree blowdown on velocity profiles, loads
   - Effects of tree blowdown on losses (overestimates effectiveness of shutters)
   - Limited treed terrain test parameters; more tests needed for
     - Larger subdivision
     - Fewer trees
     - Smaller buffers
   - Have only considered SF residential, and not commercial
10. The results show that openings should be protected in
    - Open-Suburban terrain
      - The lowest winds (110 mph) considered produced average BC>1
      - Raises question of what 100 mph results would indicate for open-suburban
    - Openings should be protected in suburban in the range 110-130 mph, depending on cost assumptions
    - For light trees, the results show reduced risk and depend on the cost assumptions

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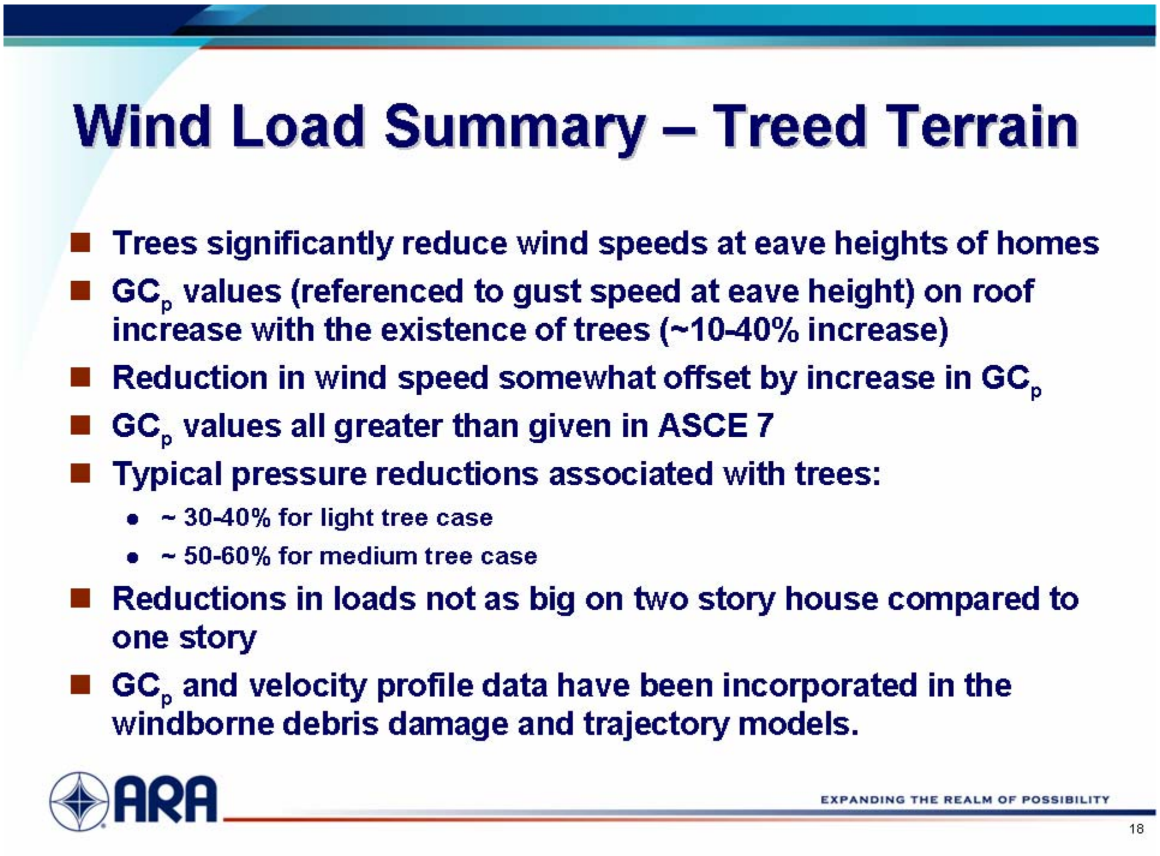
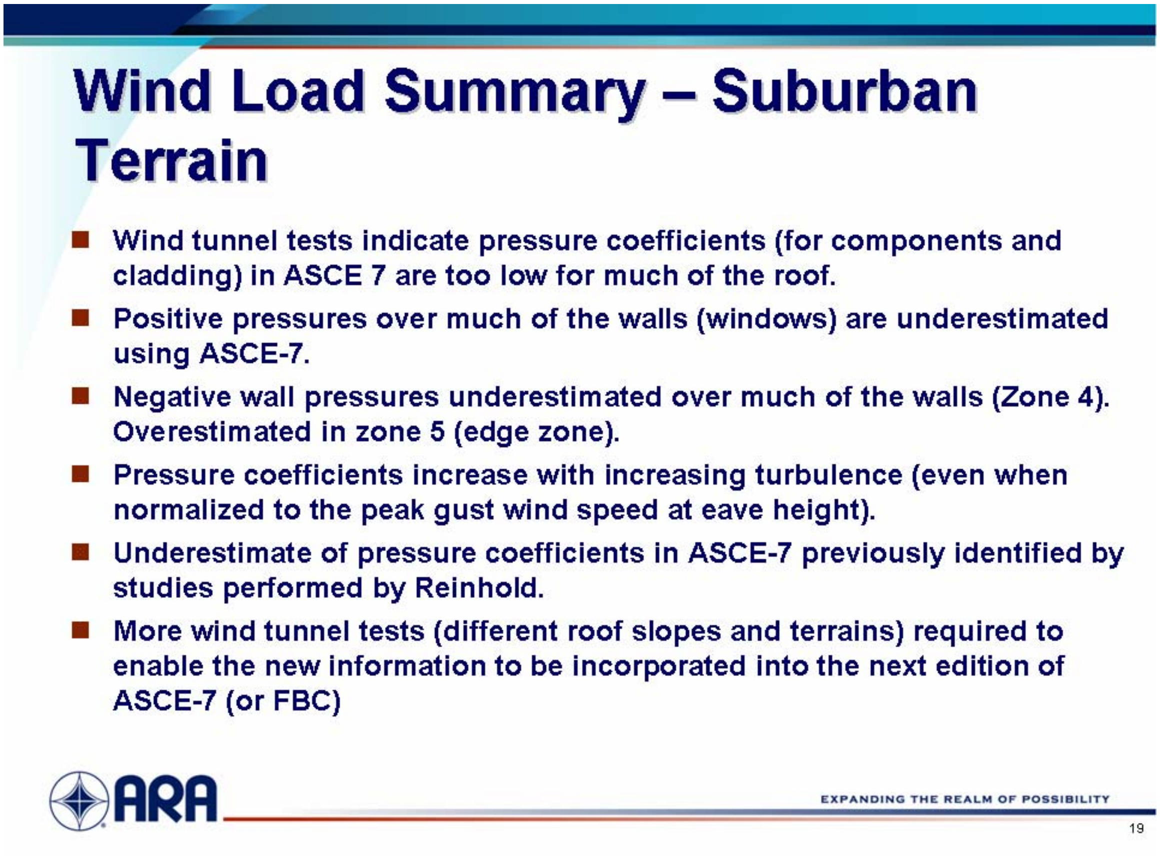
The Following Slide Set Presents Summary of Physical Data Developed by the Study from Wind Tunnel Tests and Computer Simulations of Subdivisions and Individual Houses

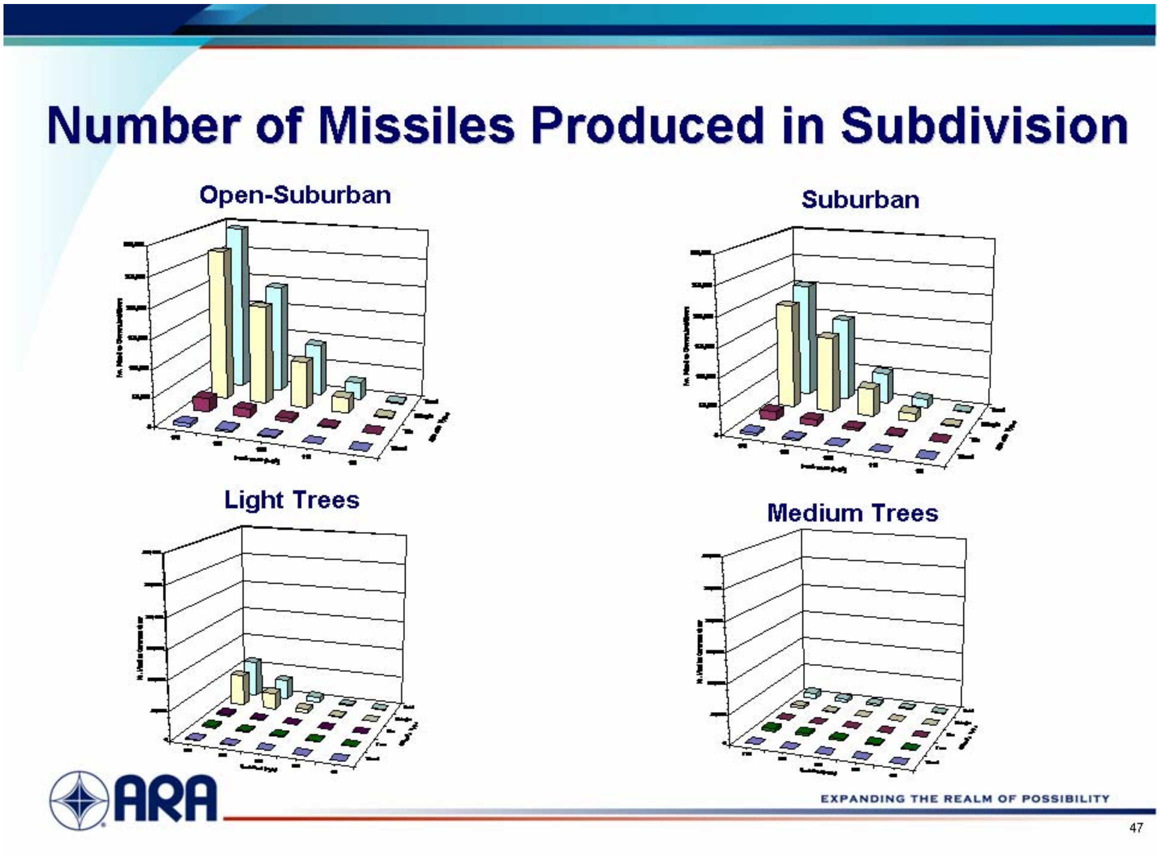
With respect to Wind Borne Debris, the significant conclusion from the wind tunnel tests is that the combined effect of decreased wind speeds and increased turbulence of the wind due to trees is to reduce pressures on structures as reported in bullet 5 below.



The following slide reports results of the wind tunnel tests that indicate weaknesses of the current ASCE 7 design procedure for wind pressures for roof and wall in terrain without trees which should be corrected in future editions of the standard based on data from this study and additional tests.



This slide indicates the simulation model's prediction of the reduction of missiles (primarily roof debris) due to the effect of trees.



Six houses with characteristics determined from actual houses built in the Florida Panhandle were modeled in the study. Below is the summary of their characteristics.

Panhandle House Summary

House	No. Stories	Roof Shape	Total SF	Normal Replacement Cost ($1,000's)	Openings		Glazing (SF)[2]	Glazing as % Wall Area
					Windows	Doors[1]		
1	2	Gable	2,536	$180-211	23	3 (3)	278 (83)	8.53%
2	2	Gable	3,938	$293-343	23	5 (3)	379 (119)	10.87%
3	1	Hip w/Gables	3,602	$283-332	17	3 (1)	300	12.23%
4	1	Hip	3,563	$249-292	16	3 (1)	287	10.62%
5	1	Gable	2,536	$189-222	8	2 (1)	229	9.43%
6	1	Hip w/Gables	1,661	$118-122	6	2 (1)	63	3.52%

[1] Garage doors in parenthesis

[2] The SF of second floor glazing is in parenthesis

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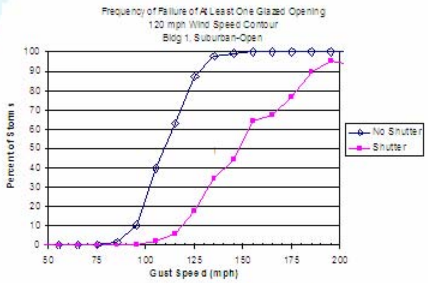
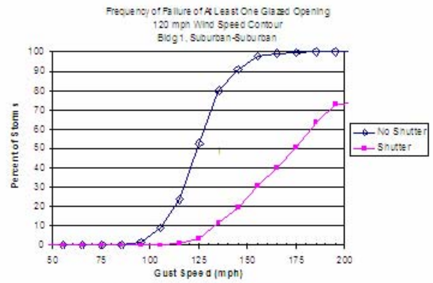
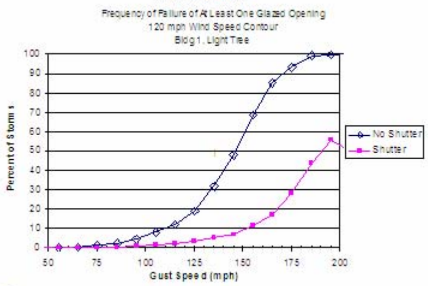
The data for the following six slides was developed by modeling the performance of each of the 6 houses at a Panhandle location corresponding to the 120 mph design wind contour. Each slide indicates the results for one house.
The graphs indicate the percentage of storms which reach wind speeds between 50 and 200 mph that will result in at least one window in the building being broken by Wind Borne Debris both with and without shutters.
Four different graphs, one for each shielding case – suburban-open, suburban-suburban, light tree and medium tree -, are presented.

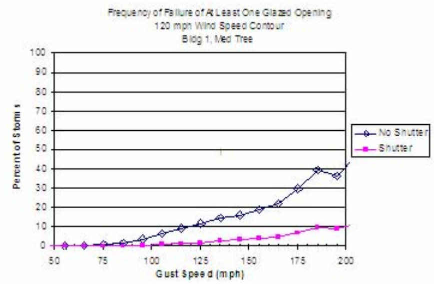
These graphs demonstrate the impact of trees on the probability of window breakage for each of the different building configurations.
The trend is the same for each of the 6 study houses. Trees dramatically reduce the probability of window breakage over time and exposure to multiple storms of varying strength.

Building 1 – Failure of at Least One Glazed Opening

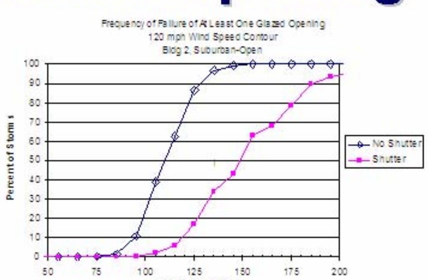


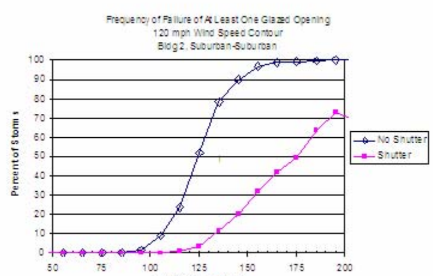


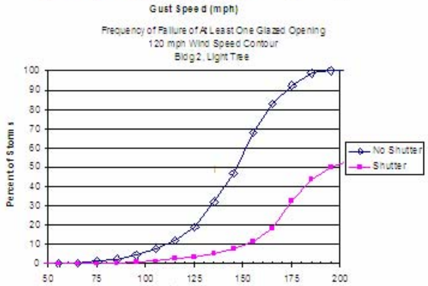


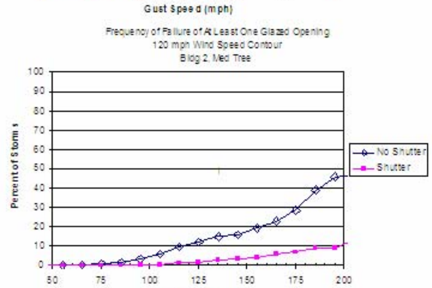


Building 2 – Failure of at Least One Glazed Opening

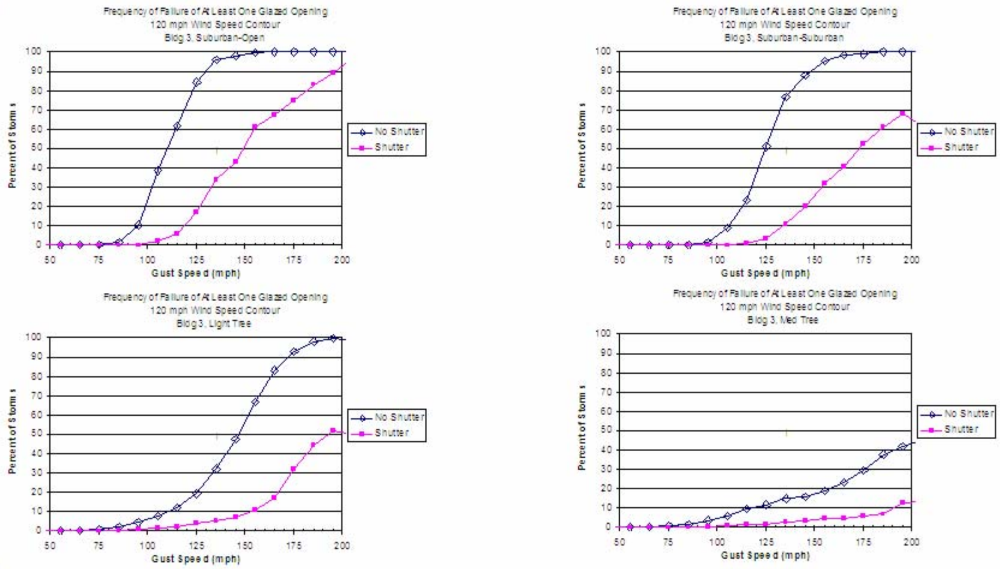








Building 3 – Failure of at Least One Glazed Opening



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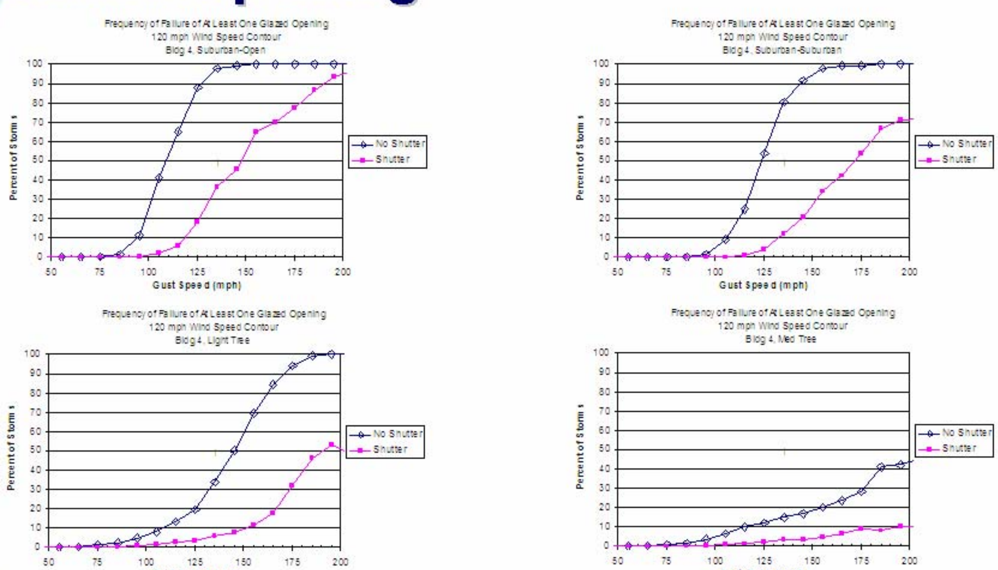
Building 4 – Failure of at Least One Glazed Opening



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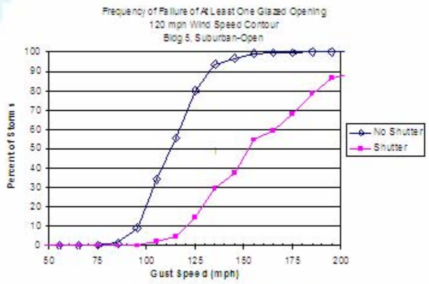
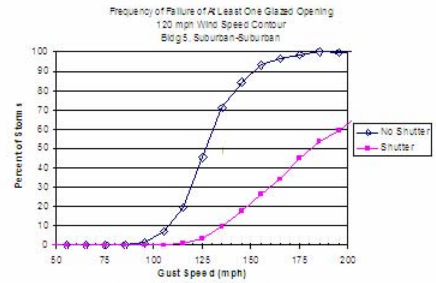
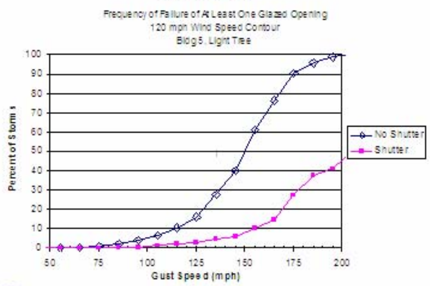
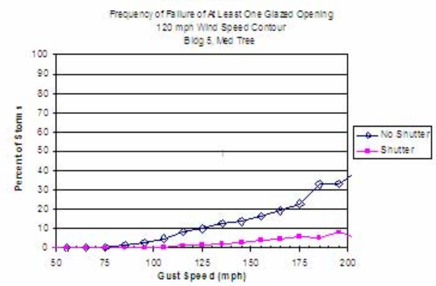
Building 5 – Failure of at Least One Glazed Opening









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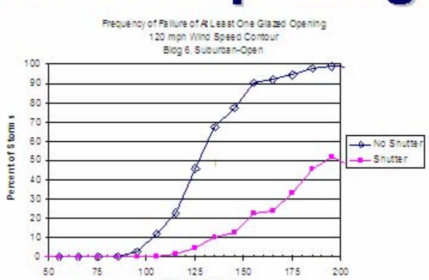
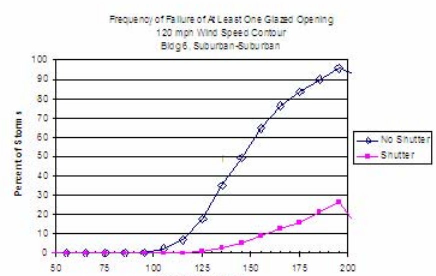
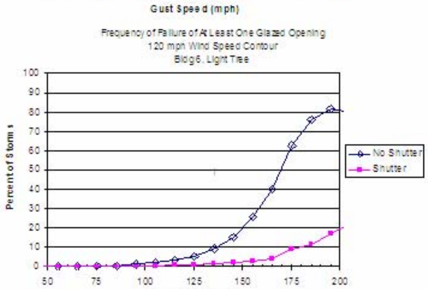
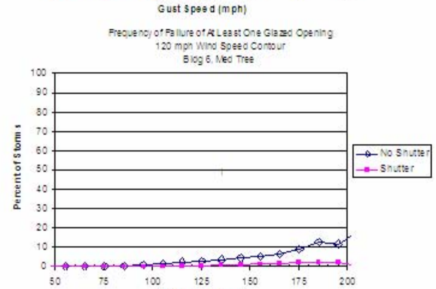
Building 6 – Failure of at Least One Glazed Opening









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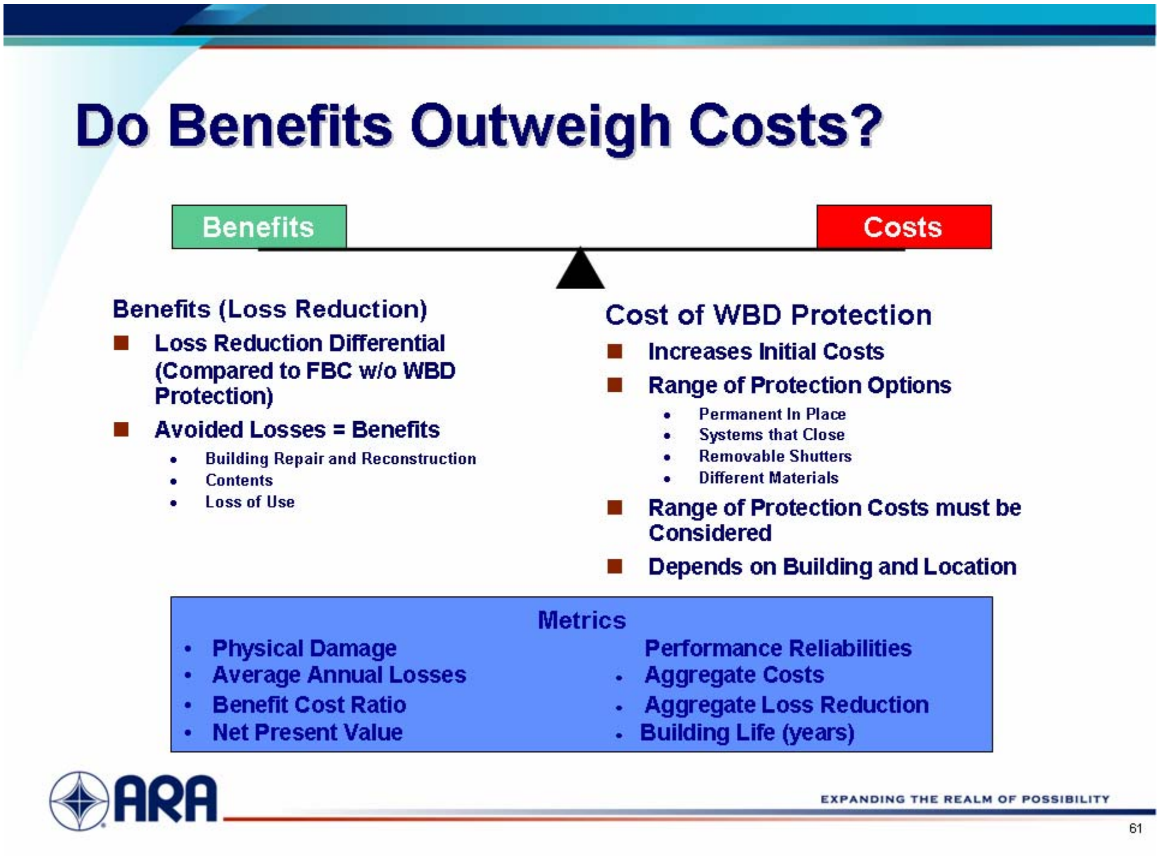
The Following Slide Set Presents A Summary of Benefit Cost Analyses Conducted Using the Simulated Performance of the Six Study Houses in a Typical Subdivision

Once the decision is made to regulate opening protection from Wind Borne Debris, determining what is cost effective to the individual and to society is a common consideration for establishing regulatory limits. The study developed benefit/cost ratios based on assumptions characteristic of an individual's perspective versus society's perspective.



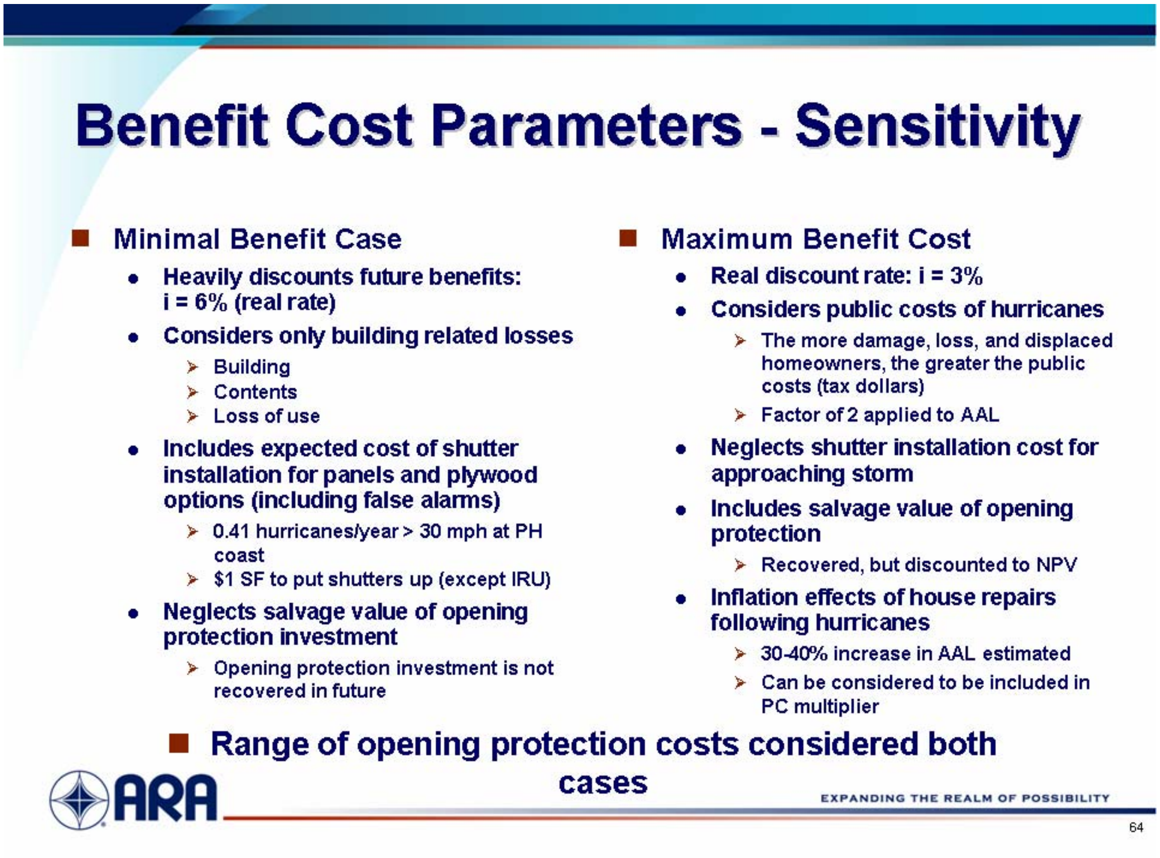
Benefits and Cost

- Benefit-Cost Decisions
  - Facilitates efficient allocation of society's resources
  - Selection of optional policy from several alternatives
  - Generally applied to specific projects, decisions, etc.
  - Generally recommend alternative with largest net societal benefits
  - Sensitivity analyses help assess how uncertainties affect results
- Benefits
  - Reduction in losses due to protection of openings
  - Considered as annualized losses
    - AAL (No Opening Protection) – AAL (Opening Protection)
  - Depends on house and type of opening protection
- Costs
  - Incremental cost of opening protection in Year 0
  - Depends on house
  - Depends on type of opening protection
- Benefit-Cost Ratio

$$R = \frac{NPV(Benefits)}{NPV(Costs)}$$

R > 1 means that Benefits > Cost

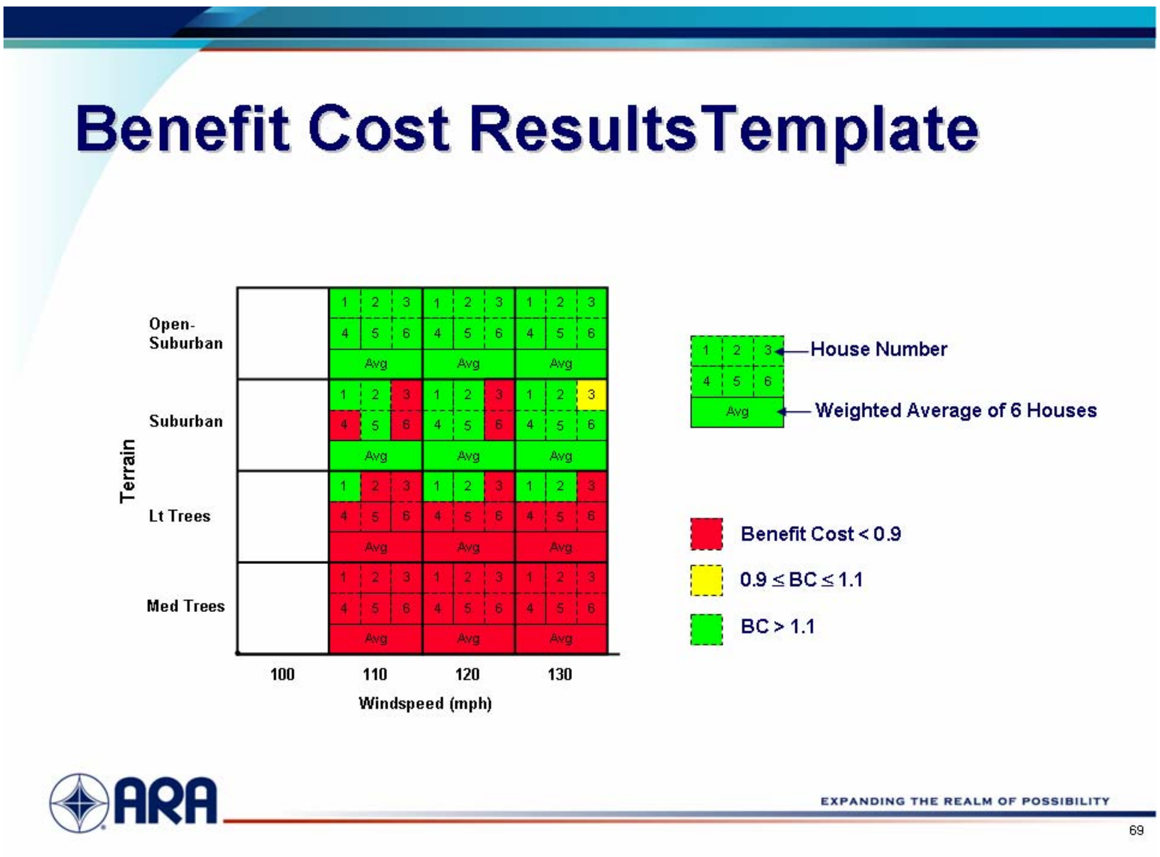
In comparison, the individual's economics would reflect lesser benefit than societal economics so "minimum benefit case" in this slide is an indicator of the individual's perspective and "maximum benefit case" is an indicator of the societal perspective.



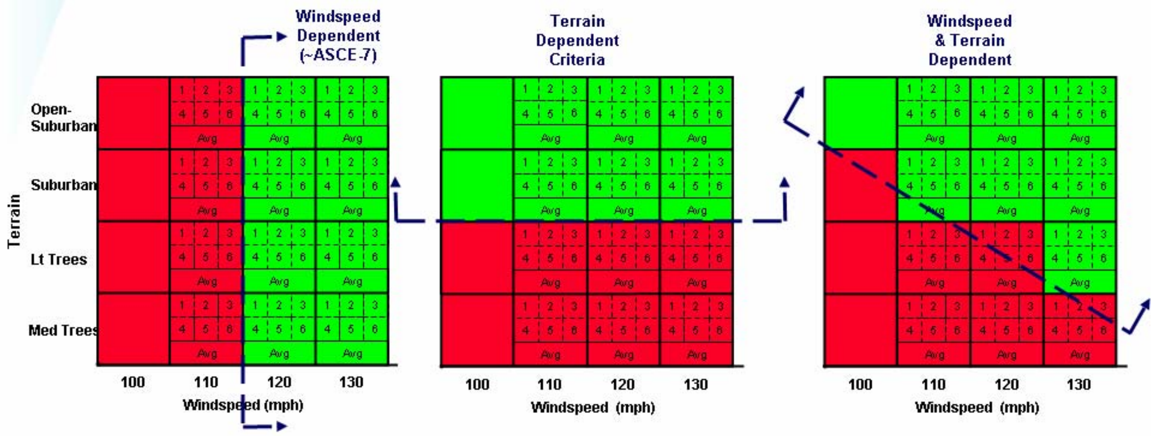
The following slides are difficult to grasp at first but after looking closely they are a good way of demonstrating when opening protection is cost effective, i.e. benefits exceed costs so the ratio, benefits/costs, is greater than one.

The important things to understand are that:
Red - means not cost effective
Green - means cost effective
Yellow - means borderline cost effective

Each graph is a grid with six cells, one for each house modeled in the study, with a single cell on the bottom row that represents the average of all six houses. If cell 1 (house 1) is green but cell 6 (house 6) is red that means window protection is cost effective for the larger house with a lot of windows but not cost effective for the smaller house with fewer windows (see slide 41 above).

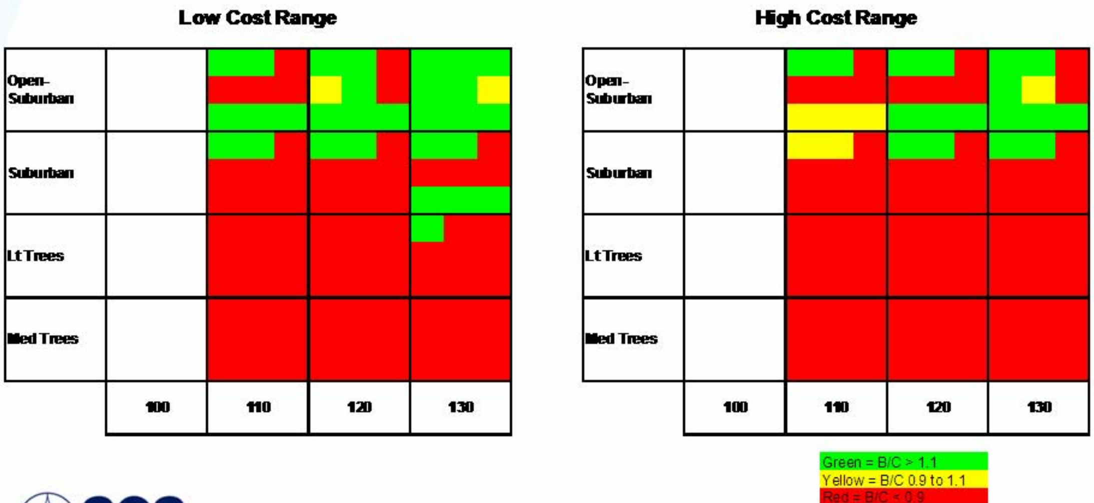


Visualizing Windspeed and Terrain Criteria



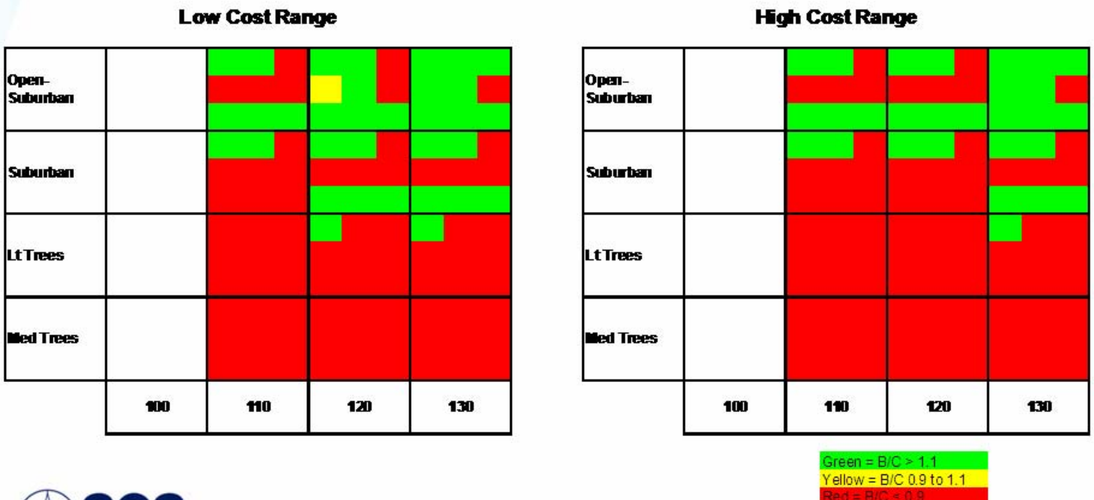
Steel Panel Shutters – Minimum Benefit Parameters

BC > 1.0 (40 yrs, I = 6%)
Public Cost Multiplier = 1, Salvage Value = 0%, Storm Installation Cost Logical = 1



Plywood Shutters – Minimum Benefit Parameters

BC > 1.0 (40 yrs, I = 6%)
Public Cost Multiplier = 1, Salvage Value = 0%, Storm Installation Cost Logical = 1



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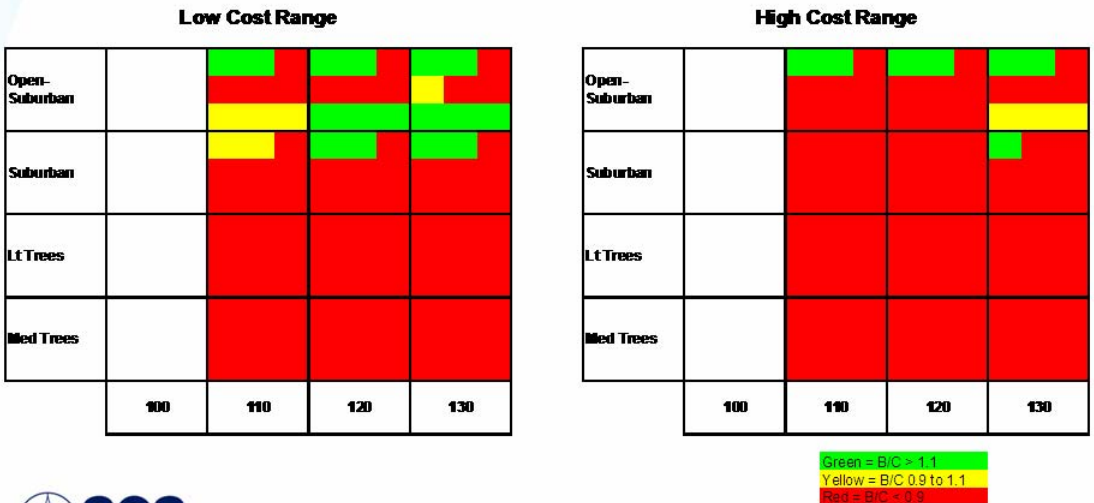
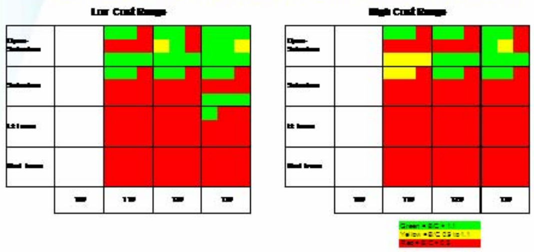
Impact Resistant Glazing – Minimum Benefit Parameters

BC > 1.0 (40 yrs, I = 6%)
Public Cost Multiplier = 1, Salvage Value = 0%, Storm Installation Cost Logical = 1

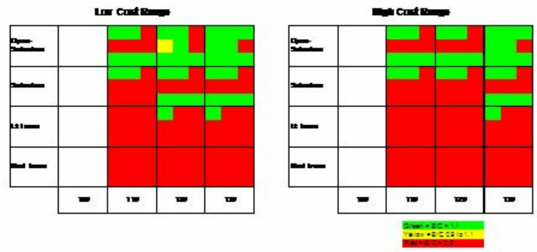


Summary – Minimum Benefit Parameters

Steel Panel Shutters
BC > 1.0 (40 yrs, I = 6%)
Public Cost Multiplier = 1, Salvage Value = 0%, Storm Installation Cost Logical = 1



Plywood Shutters
BC > 1.0 (40 yrs, I = 6%)
Public Cost Multiplier = 1, Salvage Value = 0%, Storm Installation Cost Logical = 1

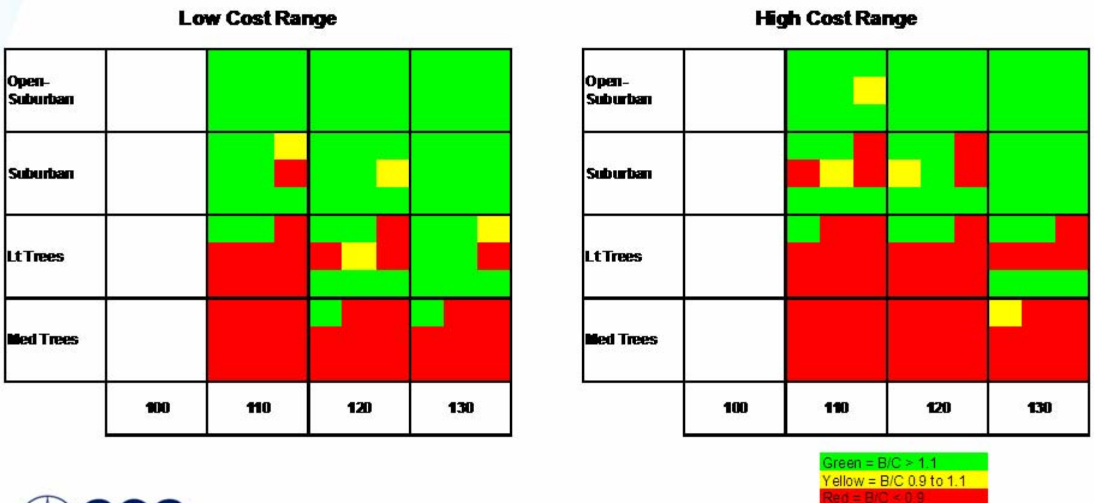


Impact Resistant Glazing
BC > 1.0 (40 yrs, I = 6%)
Public Cost Multiplier = 1, Salvage Value = 0%, Storm Installation Cost Logical = 1

Steel Panel Shutters – Maximum Benefit Parameters

BC > 1.0 (40 yrs, i = 3%)

Public Cost Multiplier = 2, Salvage Value = 100%, Storm Installation Cost Logical = 0

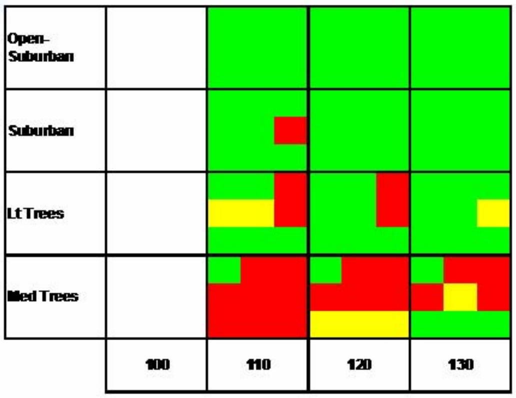


Plywood Shutters – Maximum Benefit Parameters

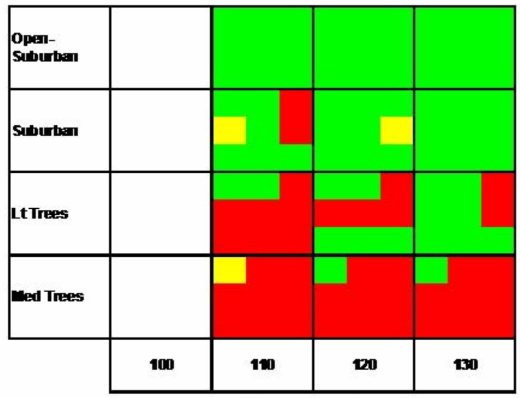
BC > 1.0 (40 yrs, i = 3%)

Public Cost Multiplier = 2, Salvage Value = 100%, Storm Installation Cost Logical = 0

Low Cost Range



High Cost Range



Green = B/C > 1.1
Yellow = B/C 0.9 to 1.1
Red = B/C < 0.9

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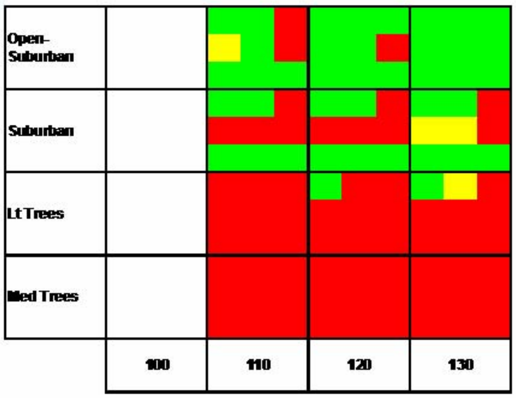
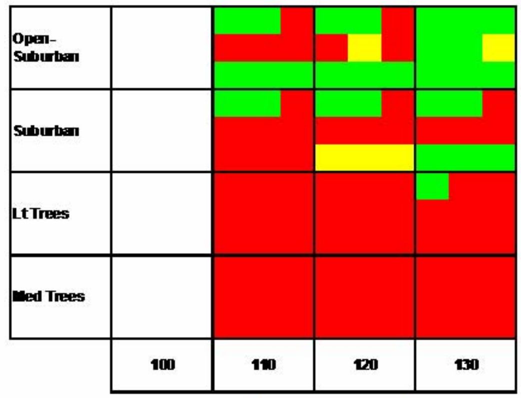
Impact Resistant Glazing – Maximum Benefit Parameters

BC > 1.0 (40 yrs, i = 3%)
Public Cost Multiplier = 2, Salvage Value = 100%, Storm Installation Cost Logical = 0

Low Cost Range



High Cost Range



Green = B/C > 1.1
Yellow = B/C 0.9 to 1.1
Red = B/C < 0.9

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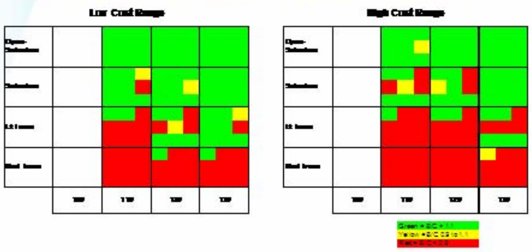
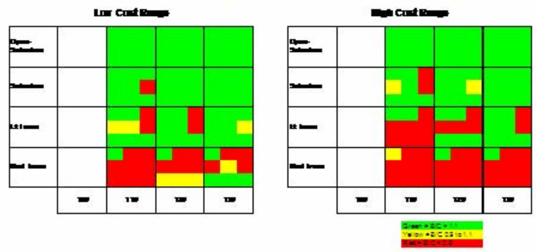
Summary – Maximum Benefit Parameters

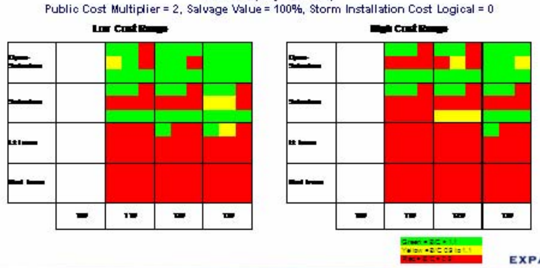
Steel Panel Shutters
BC > 1.0 (40 yrs, i = 3%)
Public Cost Multiplier = 2, Salvage Value = 100%, Storm Installation Cost Logical = 0



Plywood Shutters
BC > 1.0 (40 yrs, i = 3%)
Public Cost Multiplier = 2, Salvage Value = 100%, Storm Installation Cost Logical = 0

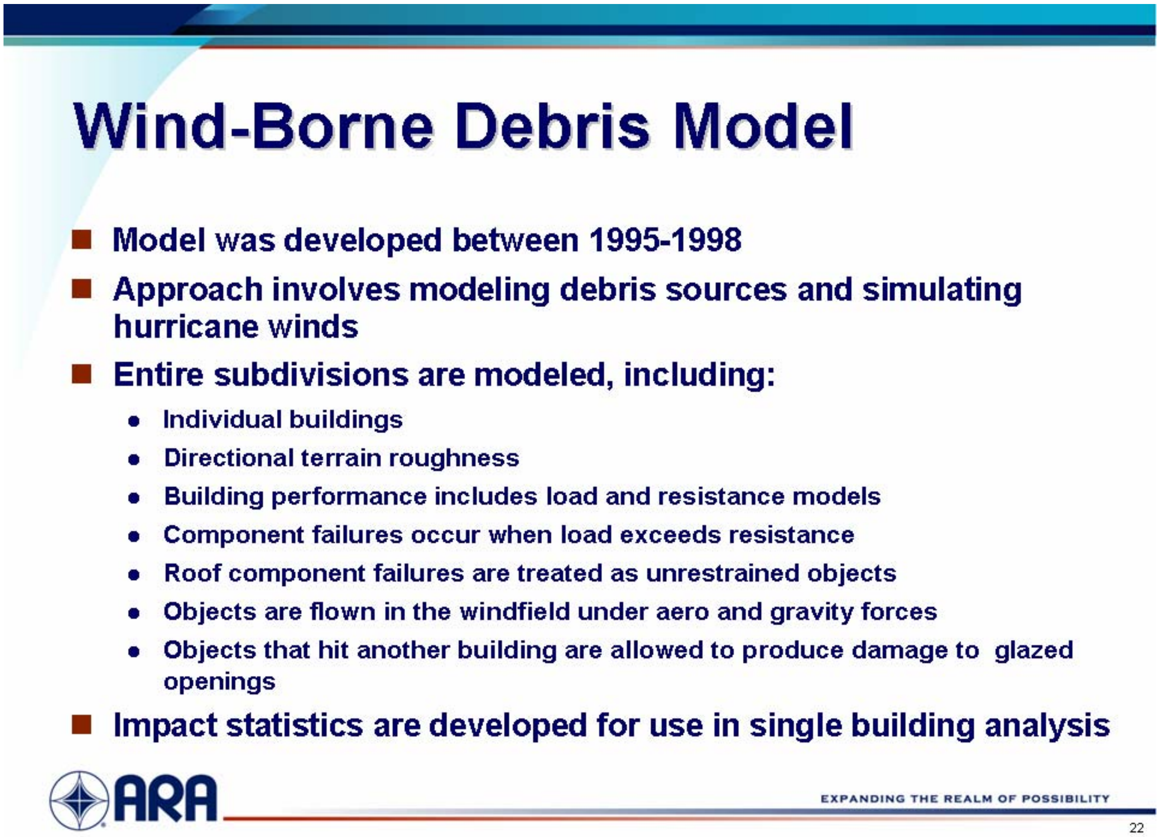


Impact Resistant Glazing
BC > 1.0 (40 yrs, i = 3%)
Public Cost Multiplier = 2, Salvage Value = 100%, Storm Installation Cost Logical = 0

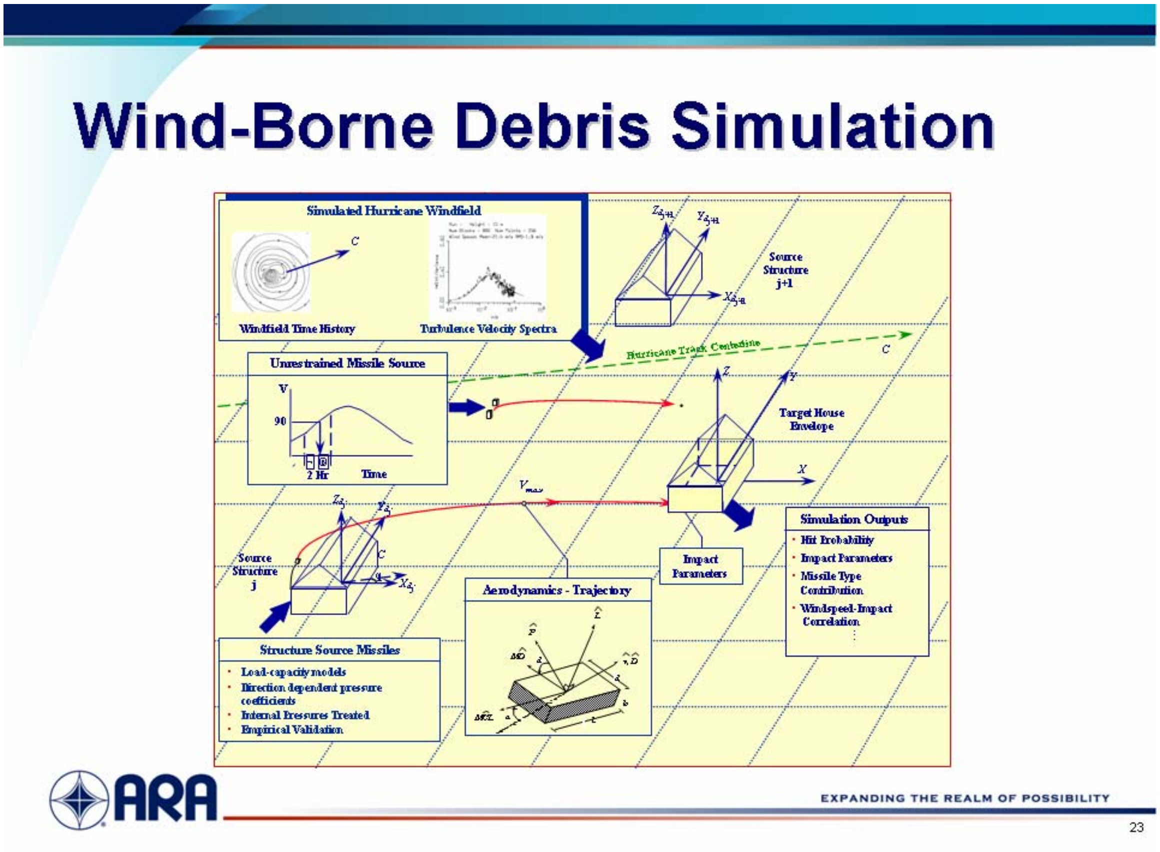


The Following Slide Set Describes the Simulation Model, the Simulations Conducted and Presents the Data for the Buildings and Window Protection Measures Investigated

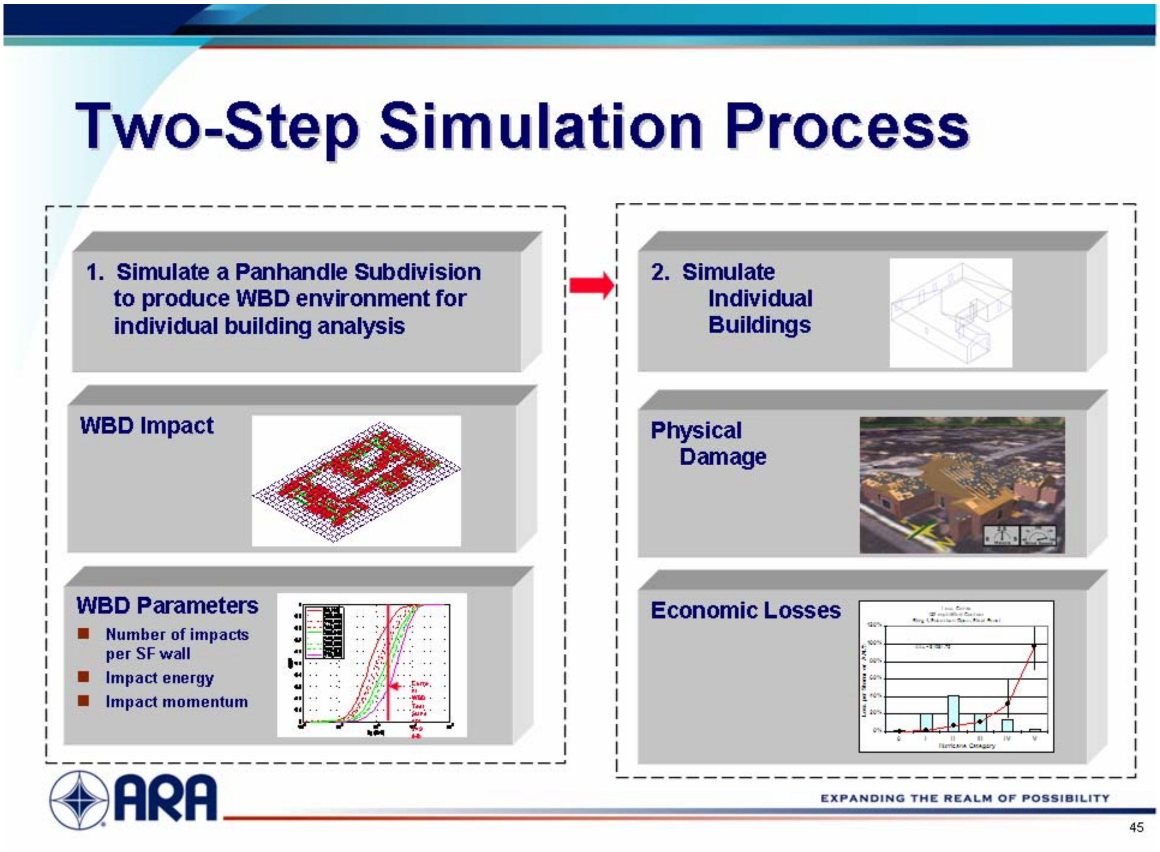
Simulation Model:



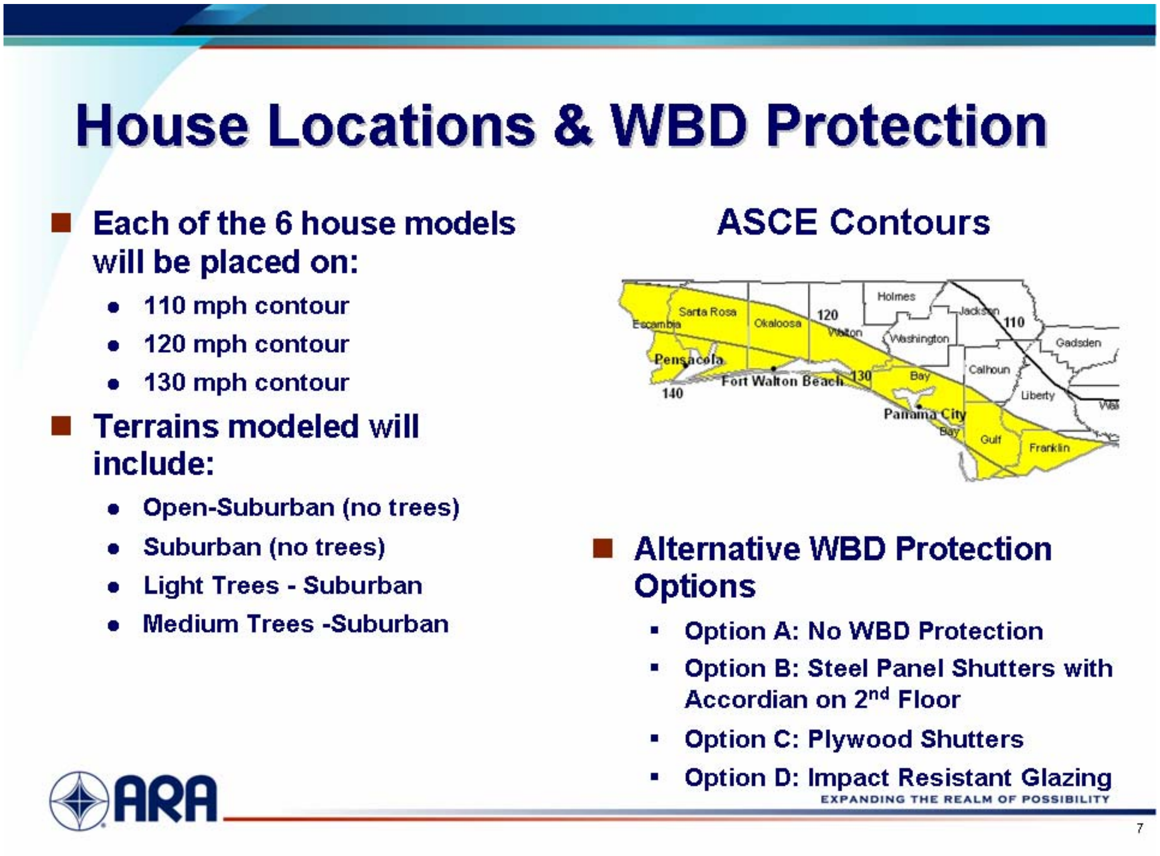
Simulation Model:



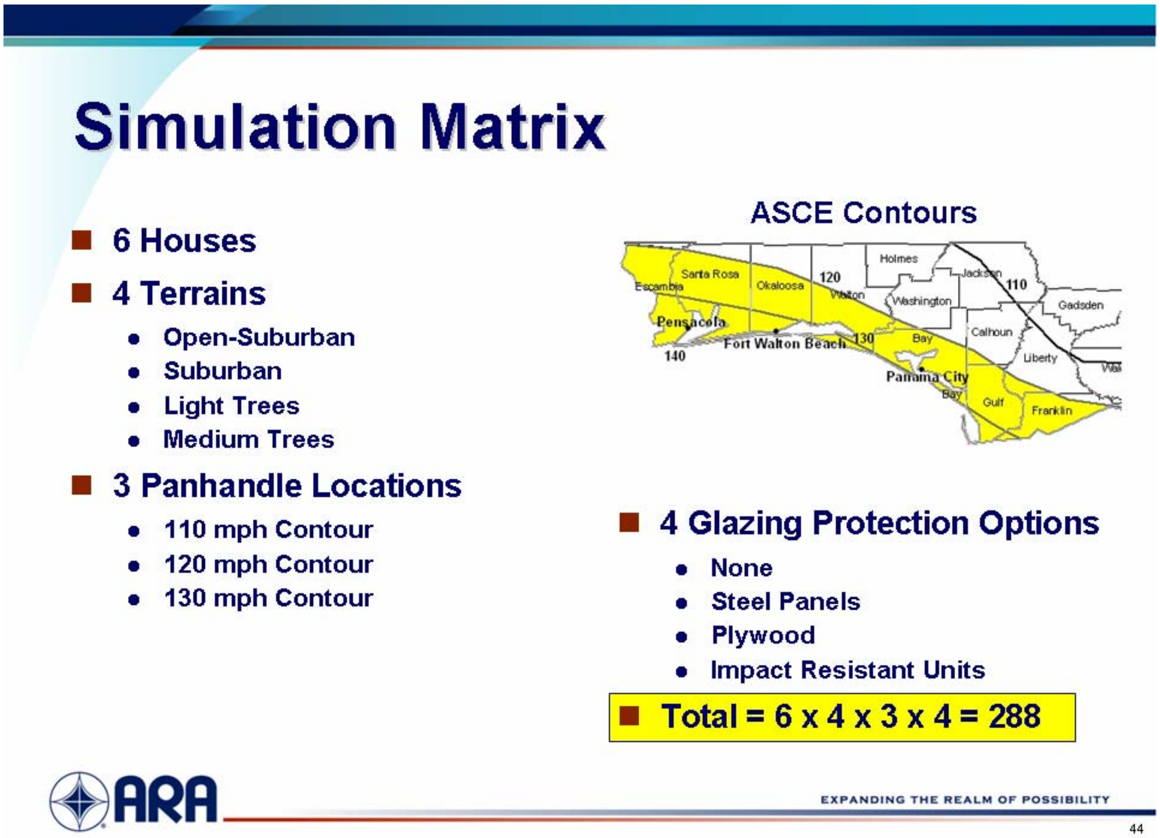
Simulation Model:



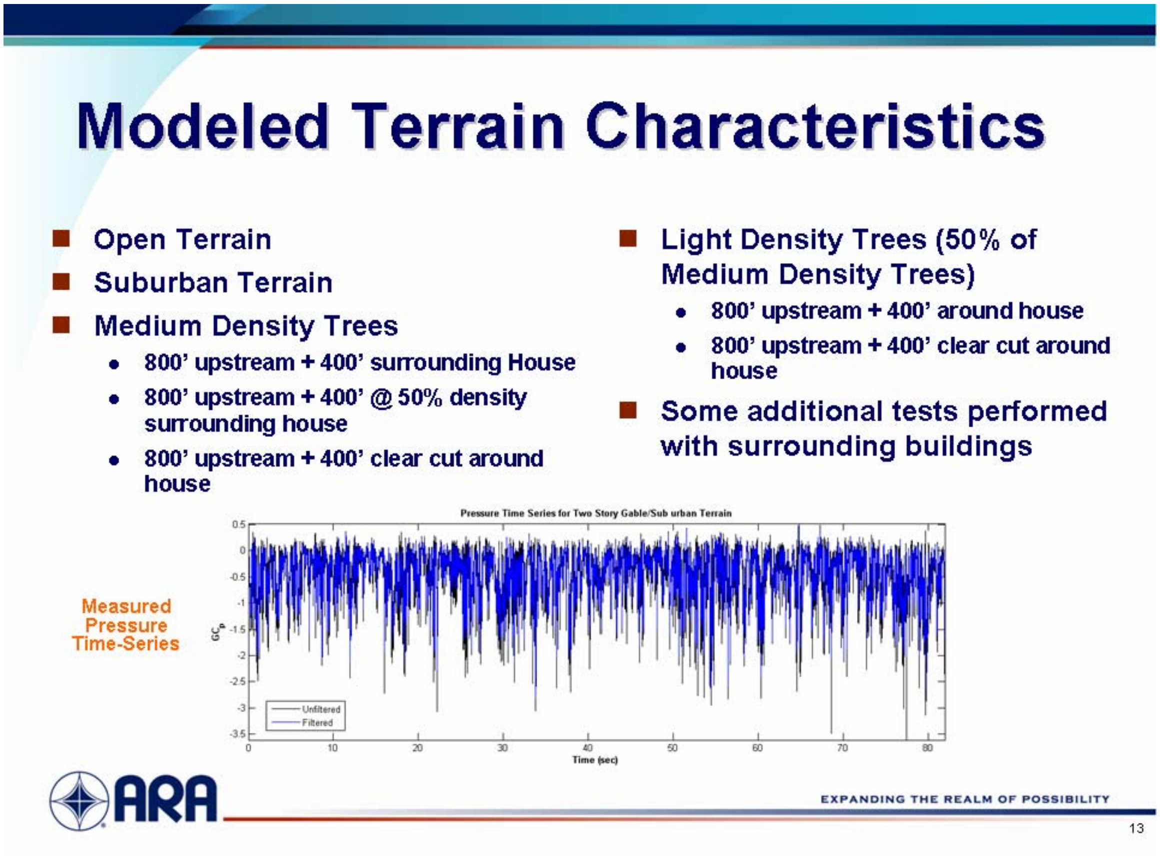
Simulations:



Simulations:



Terrain Characteristics - Simulations:



Terrain Characteristics - Simulations:

Summary: Light and Medium Tree Terrain Parameters

Tree Type	Tree Height (ft)	CdA (ft^2/tree)	Tree Density (trees/acre) for Light Trees Terrain	Tree Density (trees/acre) for Medium Trees Terrain
Deciduous	70	181	13	26
Conifer	70	69	34	68
Deciduous	50	79	30	60
Conifer	50	39	60	121
Equal Mix[1]	-	-	34	69

[1] Equal mix corresponds to 25% of each tree type and height.

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Terrain Characteristics - Simulations:

Summary: Light and Medium Tree Terrain Parameters

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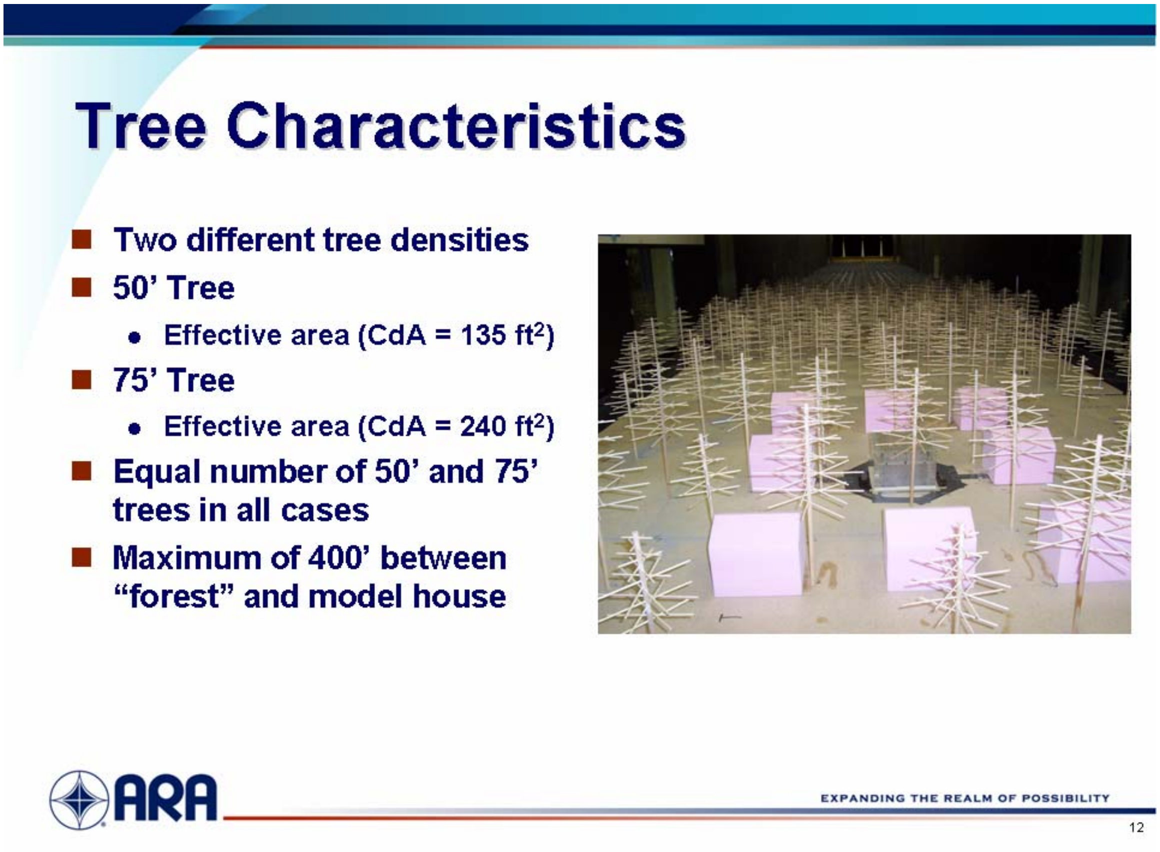
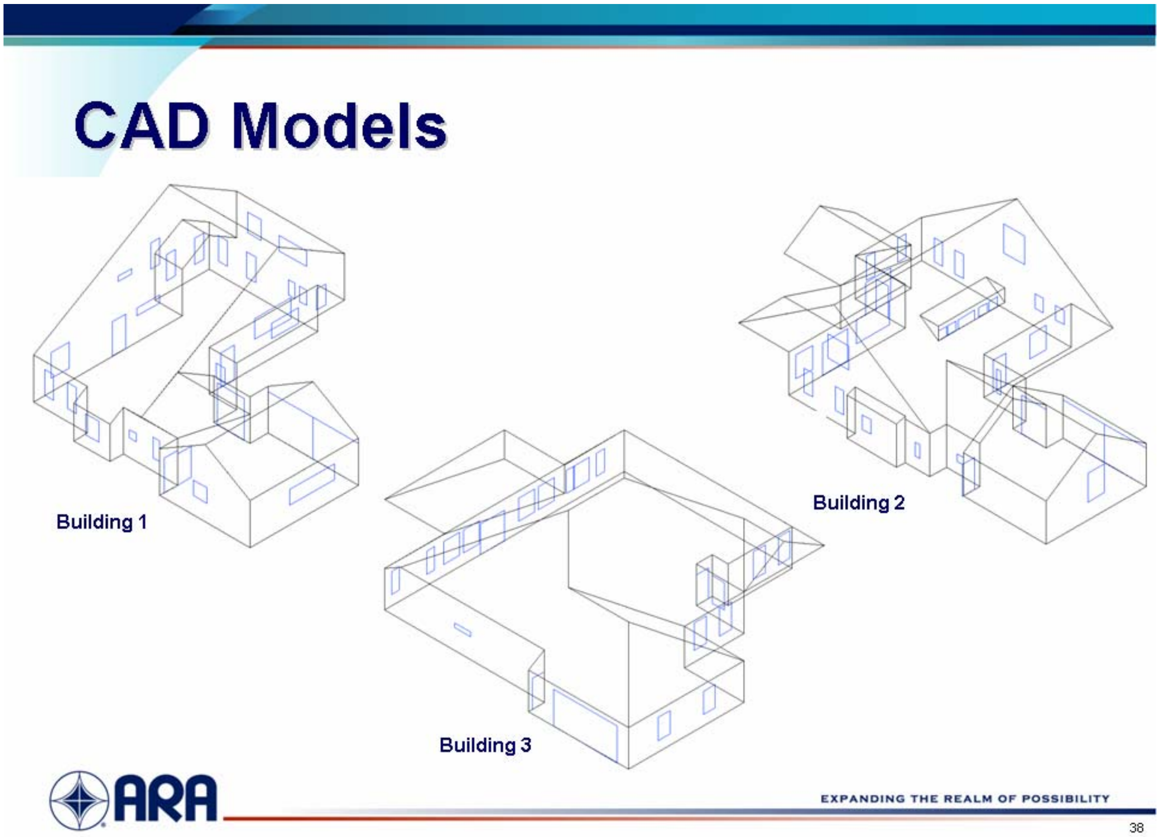
Terrain Characteristics – Wind Tunnel Tests:

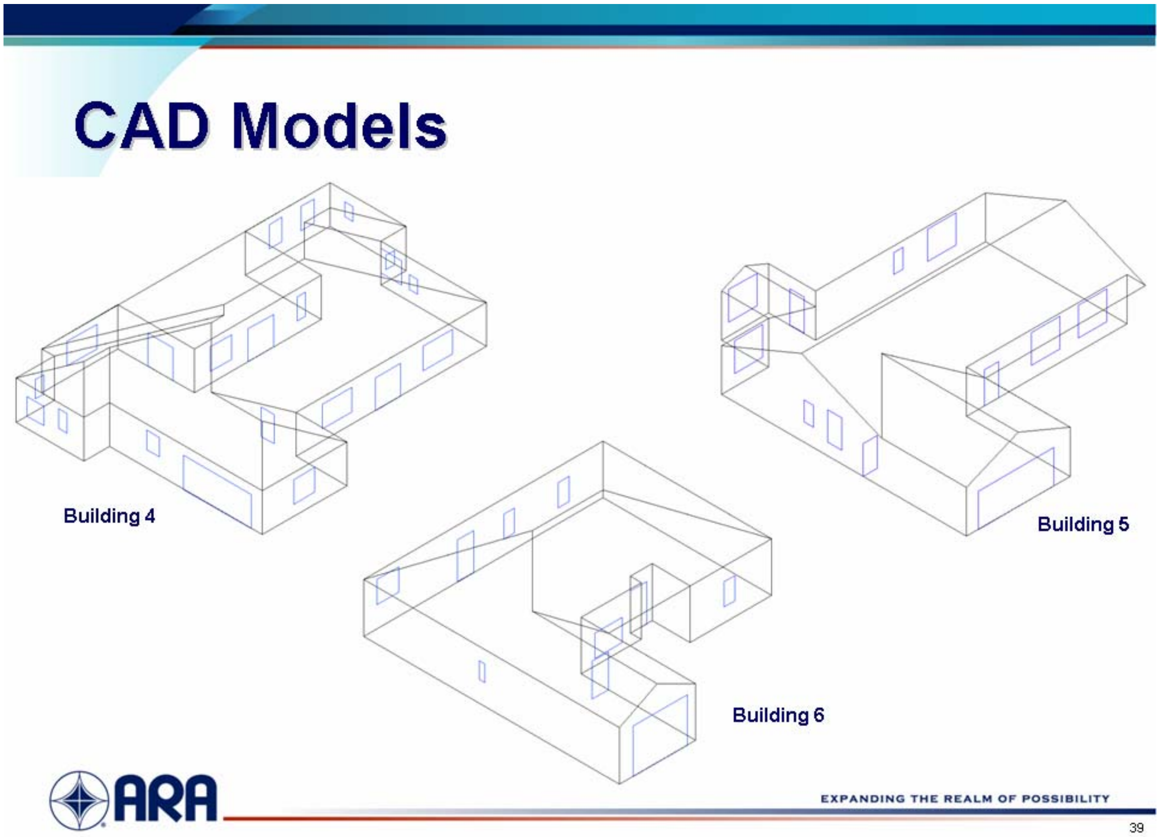


House Characteristics - Simulations:

House Characteristics:



House Characteristics:



The Following Slide Set Present the Cost Data Used in the Benefit Cost Analyses

House Characteristics:

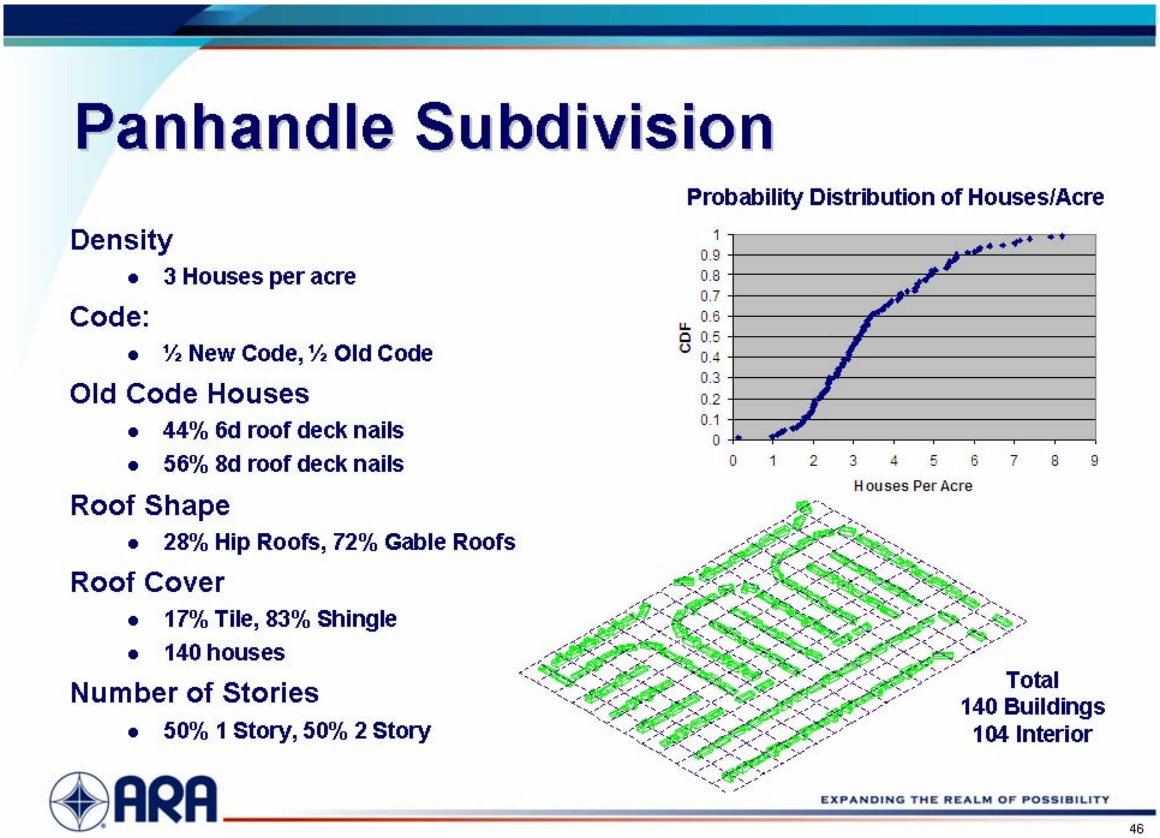
Panhandle House Summary

House	No. Stories	Roof Shape	Total SF	Normal Replacement Cost ($1,000's)	Openings		Glazing (SF)[2]	Glazing as % Wall Area
					Windows	Doors[1]		
1	2	Gable	2,536	$180-211	23	3 (3)	278 (83)	8.53%
2	2	Gable	3,938	$293-343	23	5 (3)	379 (119)	10.87%
3	1	Hip w/Gables	3,602	$283-332	17	3 (1)	300	12.23%
4	1	Hip	3,563	$249-292	16	3 (1)	287	10.62%
5	1	Gable	2,536	$189-222	8	2 (1)	229	9.43%
6	1	Hip w/Gables	1,661	$118-122	6	2 (1)	63	3.52%

[1] Garage doors in parenthesis

[2] The SF of second floor glazing is in parenthesis

Subdivision Characteristics:



House Descriptions and Costs:

Panhandle House Summary

House	No. Stories	Roof Shape	Total SF	Normal Replacement Cost ($1,000's)	Openings		Glazing (SF)[2]	Glazing as % Wall Area
					Windows	Doors[1]		
1	2	Gable	2,536	$180-211	23	3 (3)	278 (83)	8.53%
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1 Garage doors in parenthesis

2 The SF of second floor glazing is in parenthesis

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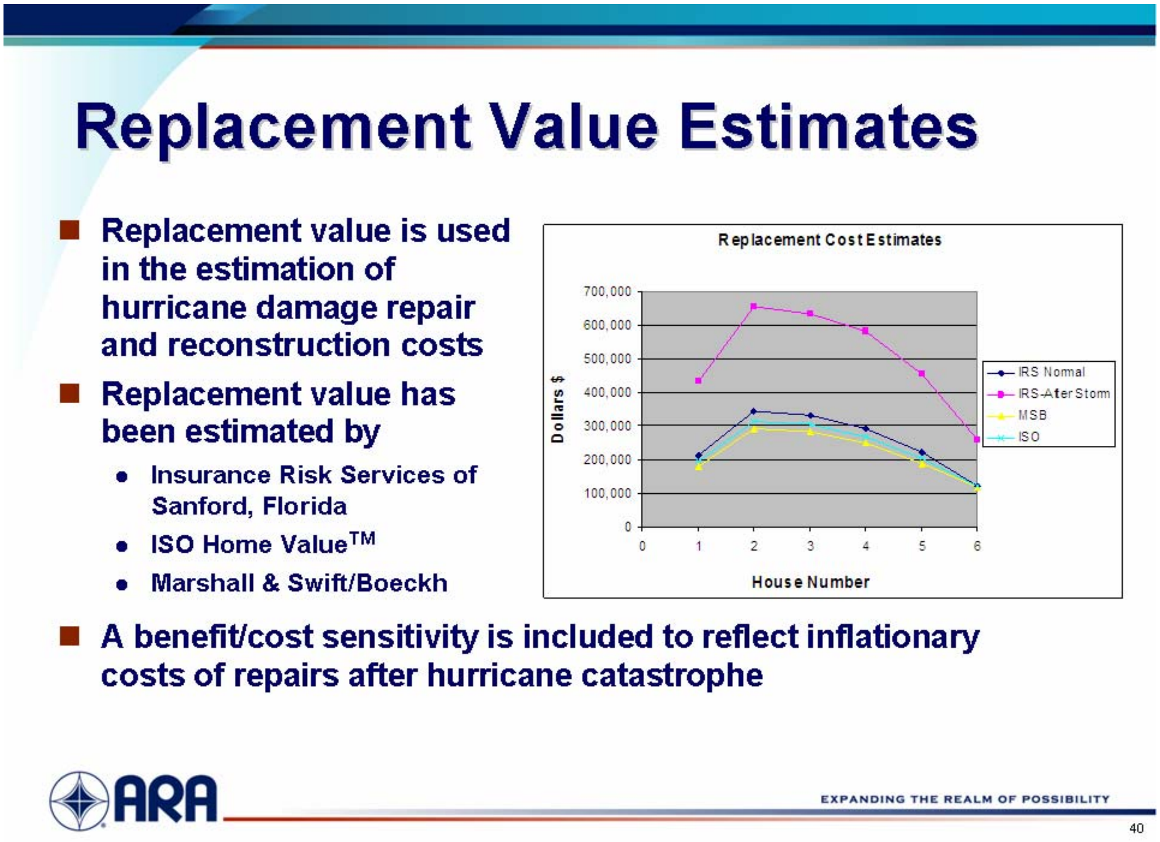
House Replacement Costs:



Window Protection Option Costs:
A range of costs was assumed for each type of protection.

Protection Option Costs

- **Glazing Protection SF Cost Estimates**

Protection Option	Cost Range ($/SF)	
	Low	High
A. Steel Panels (Accordian on 2nd Floor)	7 20	15 30
B. Plywood	3	7
C. Impact Rated Units	25	45

- **House Upgrade Costs**

	Steel Panels		Plywood		IRU	
House	Low	High	Low	High	Low	High
1	3,025	5,415	834	1,946	6,950	12,510
2	4,200	7,470	1,137	2,653	9,475	17,055
3	2,100	4,500	900	2,100	7,500	13,500
4	2,009	4,305	861	2,009	7,175	12,915
5	1,603	3,435	687	1,603	5,725	10,305
6	591*	945	339*	441	1,725	2,835

*$150 added to low cost

- **House Upgrade Cost (% of Base)**

	Steel Panels		Plywood		IRU	
House	Low	High	Low	High	Low	High
1	1.55%	2.77%	0.43%	1.00%	3.56%	6.40%
2	1.32%	2.35%	0.36%	0.84%	2.99%	5.38%
3	0.68%	1.47%	0.29%	0.68%	2.45%	4.40%
4	0.74%	1.60%	0.32%	0.74%	2.66%	4.79%
5	0.78%	1.67%	0.33%	0.78%	2.79%	5.02%
6	0.49%	0.78%	0.28%	0.37%	1.43%	2.35%

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This Briefing is a Synopsis of the Information Provided in the ARA Powerpoint Presentation for the Florida Building Commission's June 19, 2006 Meeting at Destin, Florida. For Additional Information See the Complete Presentation.