Performance of Houses in Extreme Wind

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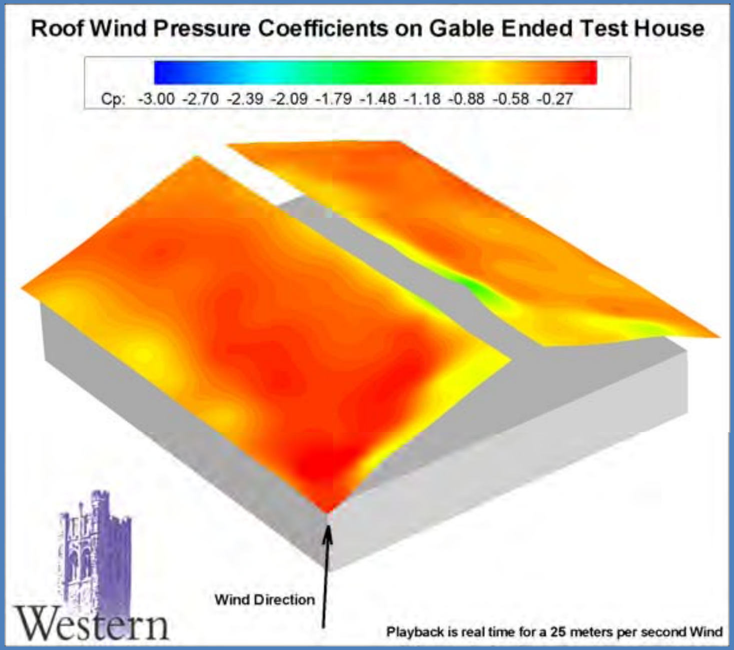
AFTER THE STORM:
Sorting through the mess

Wind-Induced Pressures on the 'Three Little Pigs' test house



We can't really understand what we see in a wind storm without understanding some aspects of the wind field, the aerodynamics of buildings, structural responses, and flight of debris.

Building Aerodynamics:

Imagine turning a house upside down…
hanging weights off the roof…
and shaking it…


Details matter to structural performance….the front doors blew in… and they toe-nails were incorrect (only 2, not 3)

…the neighbour's house (same style) was undamaged;
except for a few shingles lost.


Large opening in envelope – internal pressure – roof failure
53
WHERE DID THE ROOF GO?


Neighbour's garage roof landed on this house

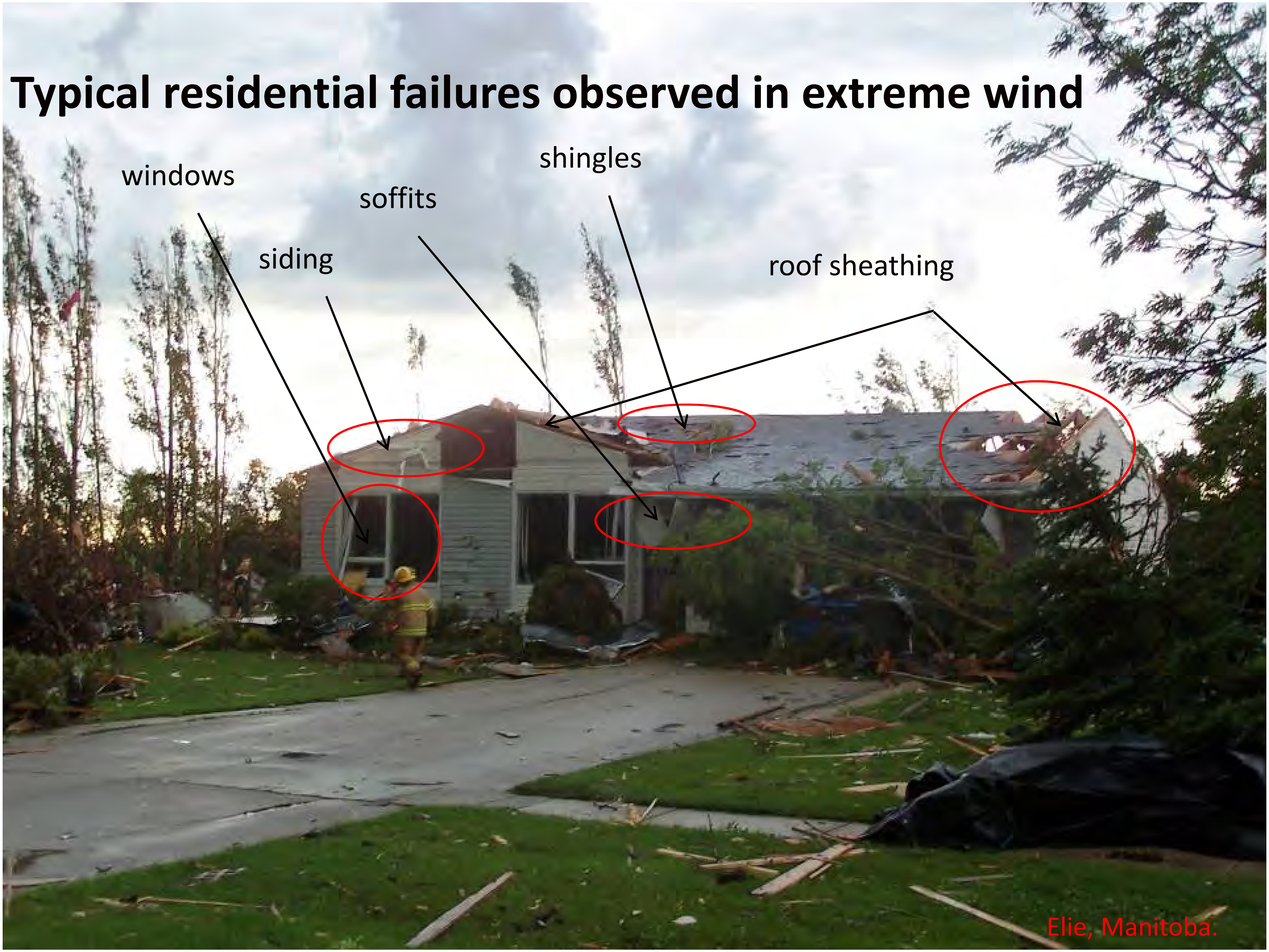
Commercial roof failures, and roof-top equipment

WIND-BORNE DEBRIS:

Failed components becoming airborne

….hit things

Typical residential failures observed in extreme wind



Objectives

With knowledge from damage surveys, we have a very good idea of what is failing and what the common problems are.

Over the past two years, there has been substantial output from the Insurance Research Lab for Better Homes, addressing many of these common problems.

The objective of the talk today is to describe some of the key findings to date.

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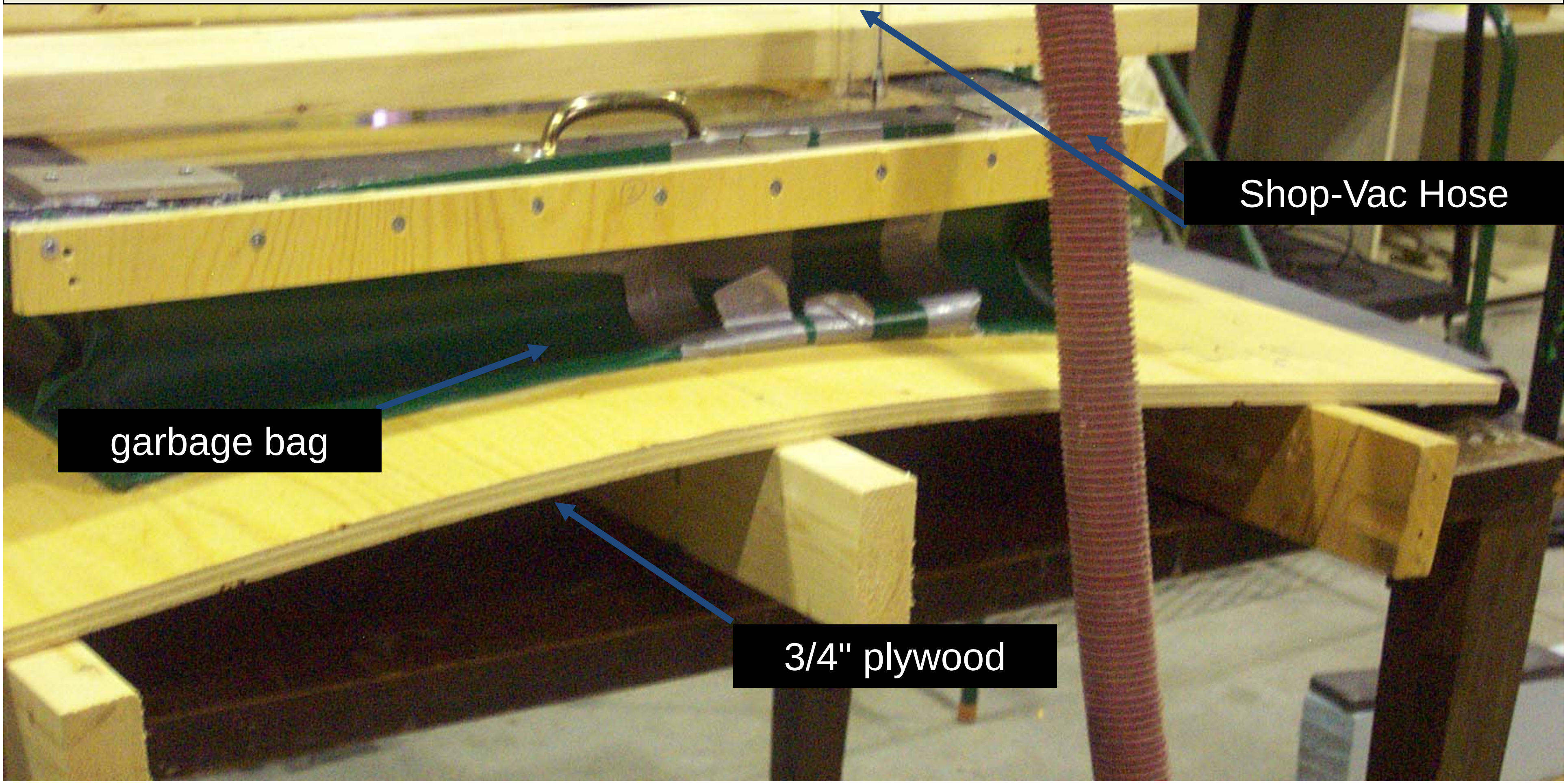
This involves two aspects:

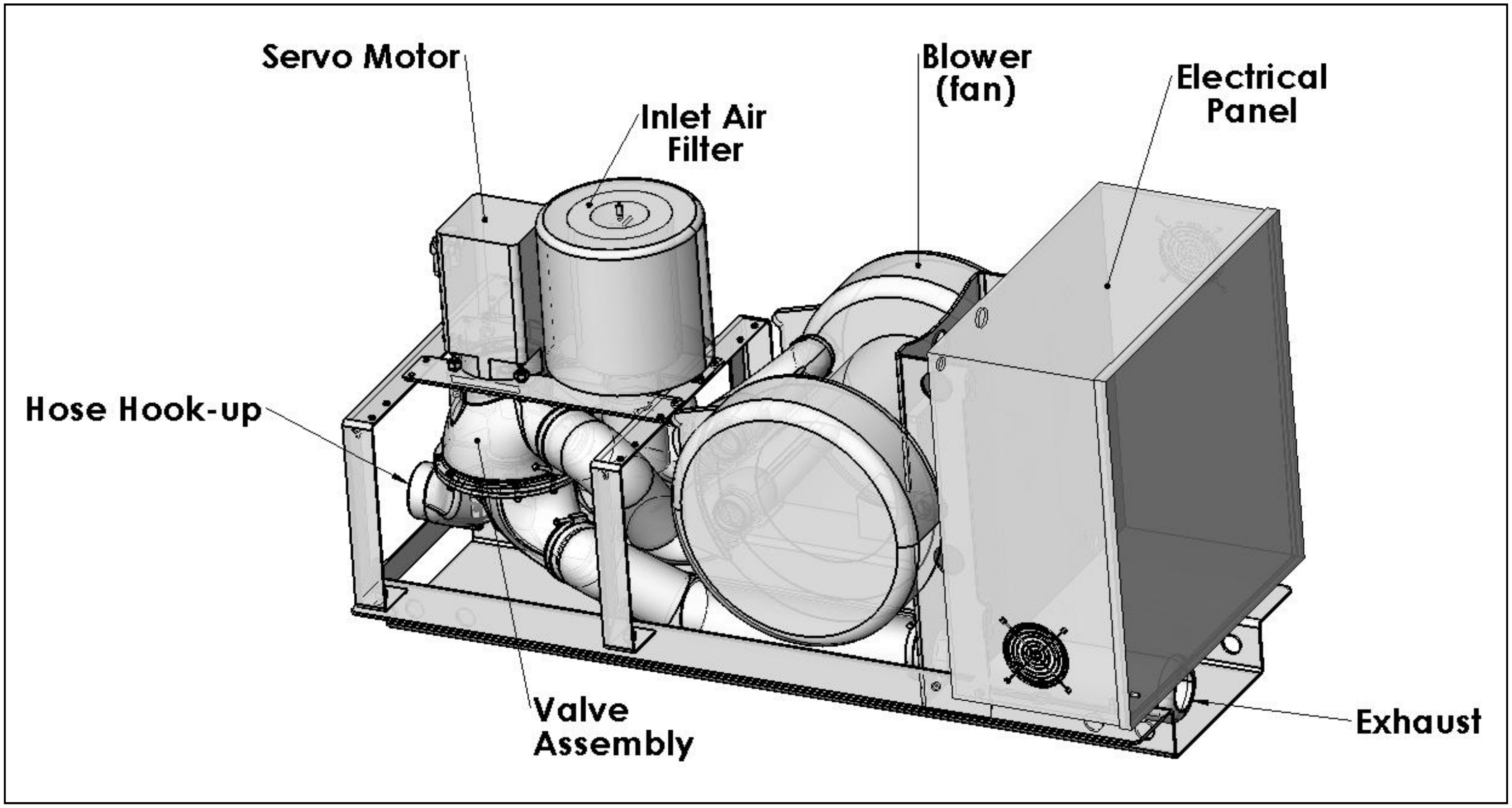
1. Developing new test methods
2. Conducting tests on the various elements which commonly fail

THE PRESSURE LOADING CONCEPT:



The loading concept is simple;
we replicate the pressures that the wind induces.
Fans are used, NOT TO BLOW WIND, but more like a vacuum cleaner

Development of New Test Methods: the PLA



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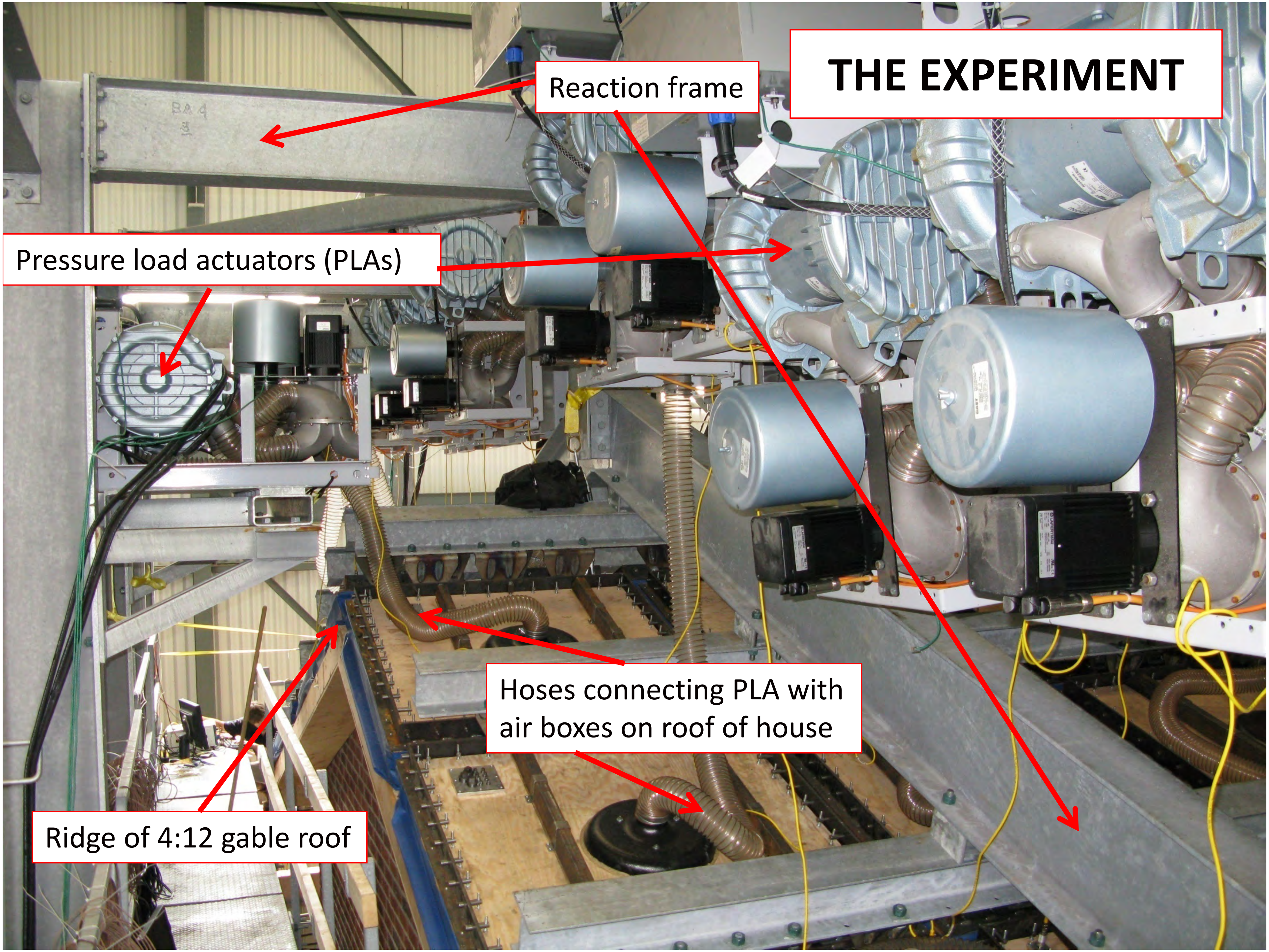
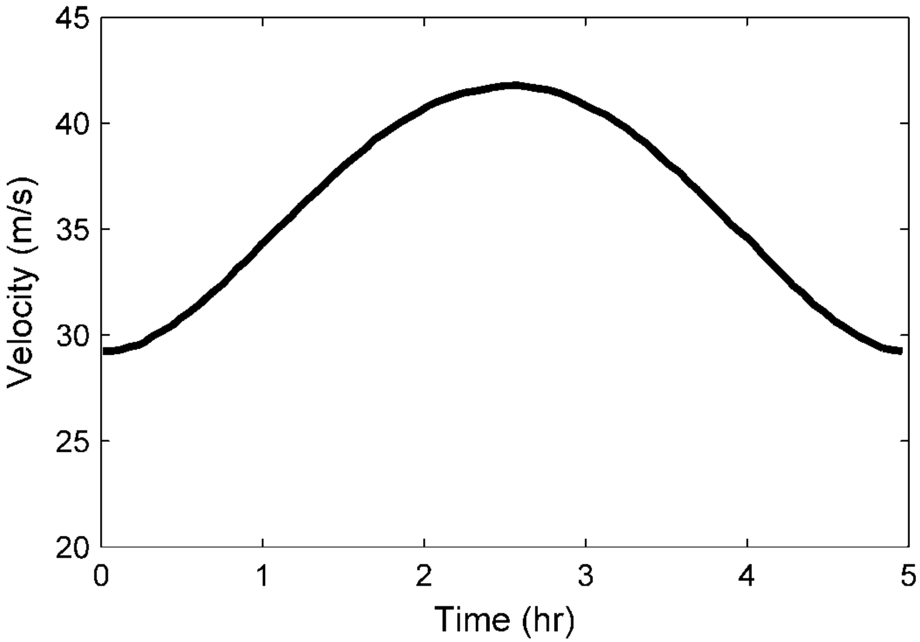
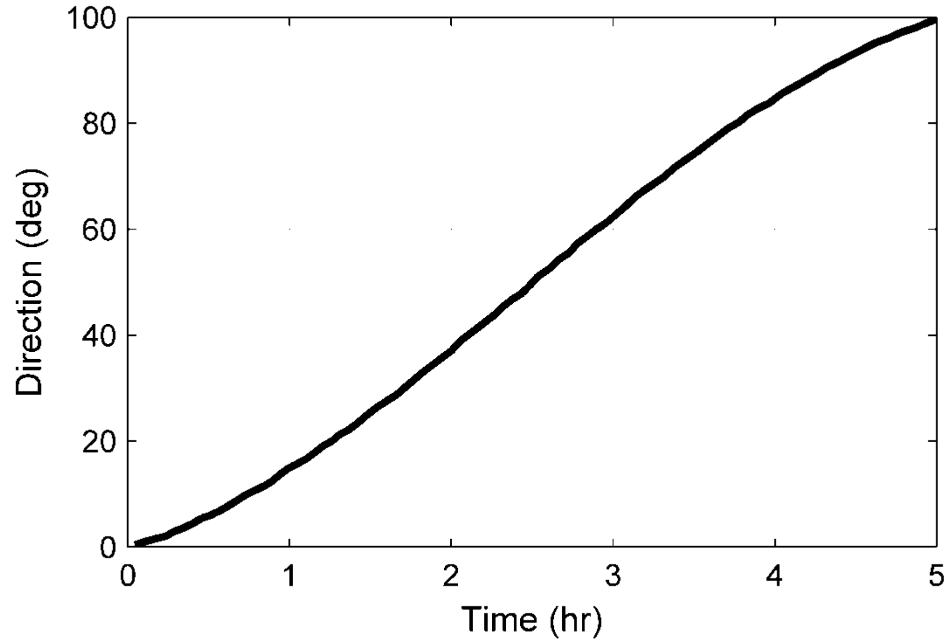
TESTS on FULL-SCALE HOUSES: How do we do it?


THE EXPERIMENT
Reaction frame
Pressure load actuators (PLAs)
Hoses connecting PLA with air boxes on roof of house
Ridge of 4:12 gable roof

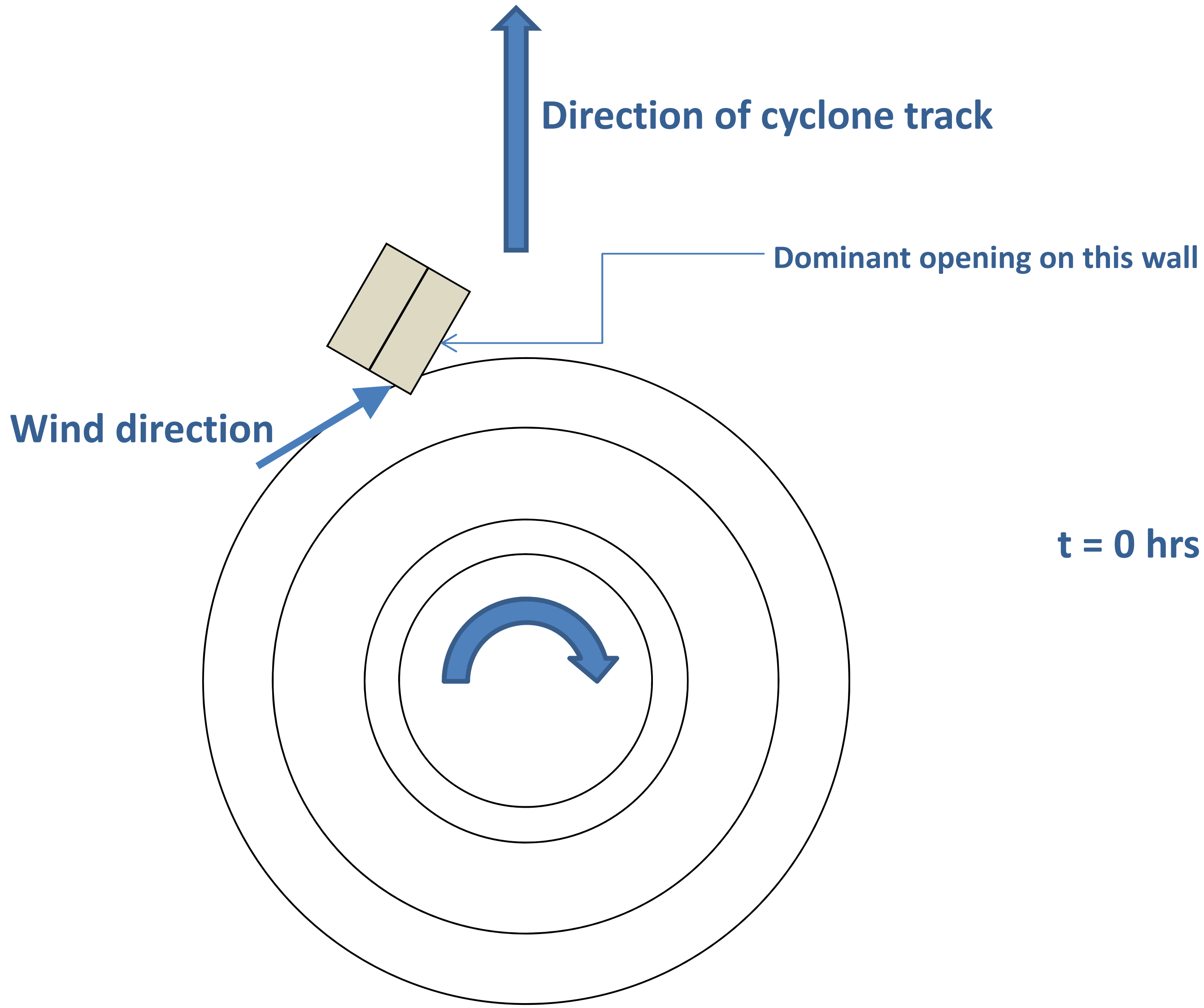
What if we could apply a hurricane or tornado to this house? or to part of the house?



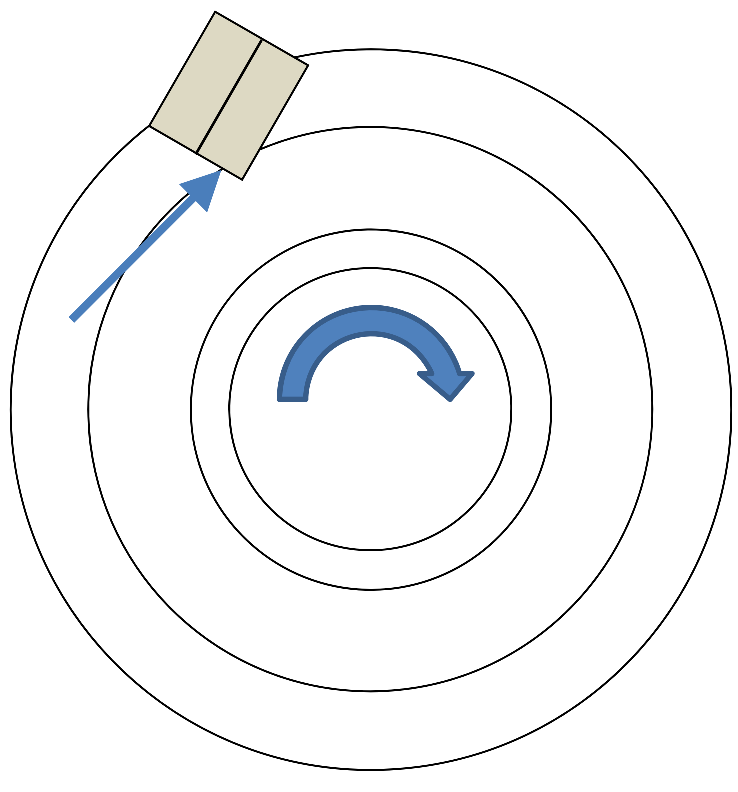


Angle of wind on building

Wind rotation in clockwise direction (Southern hemisphere)

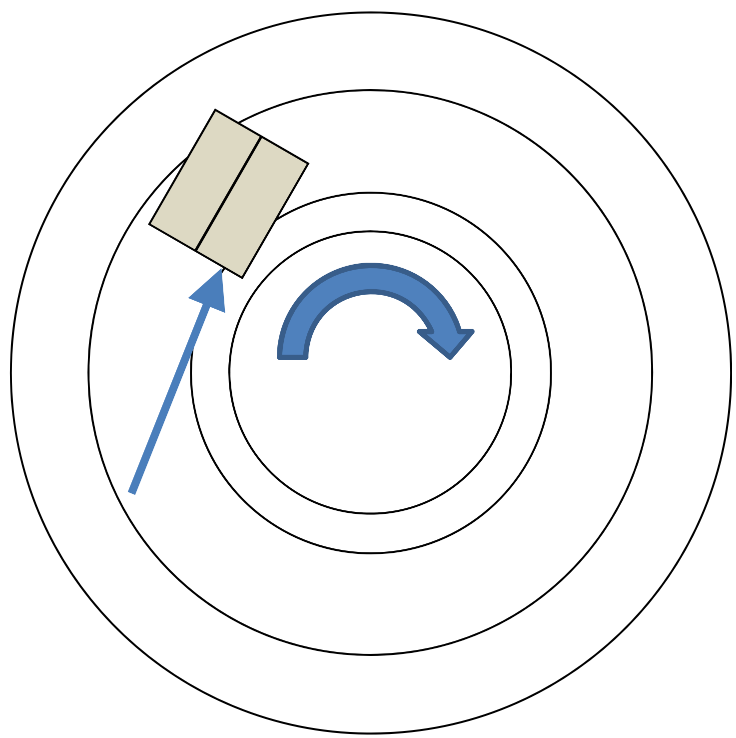


Wind rotation in clockwise direction (Southern hemisphere)



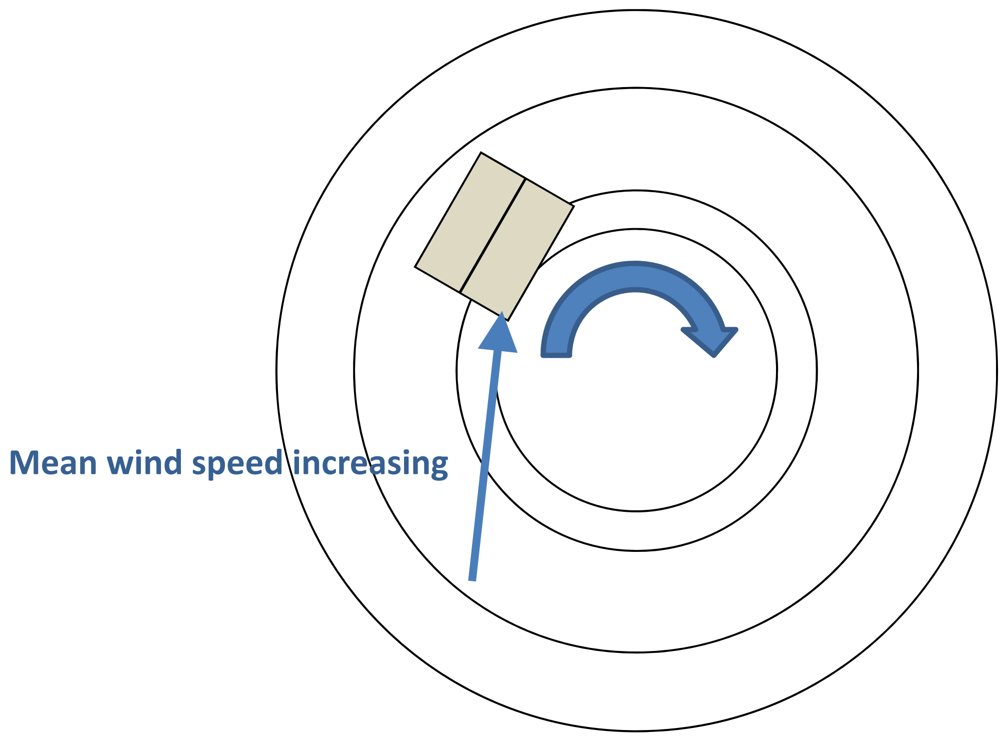
t = 1 hrs

Wind rotation in clockwise direction (Southern hemisphere)



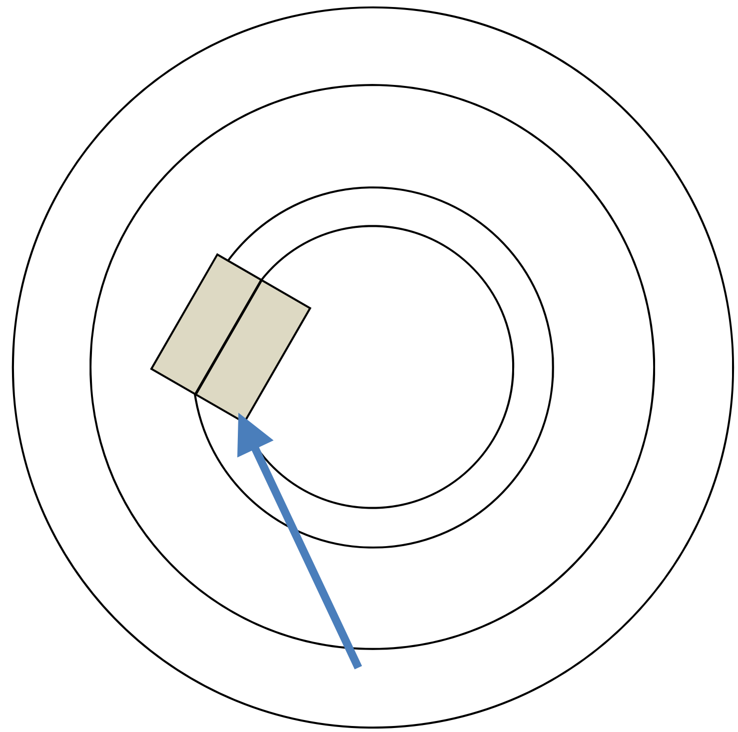
t = 1.5 hrs

Wind rotation in clockwise direction (Southern hemisphere)



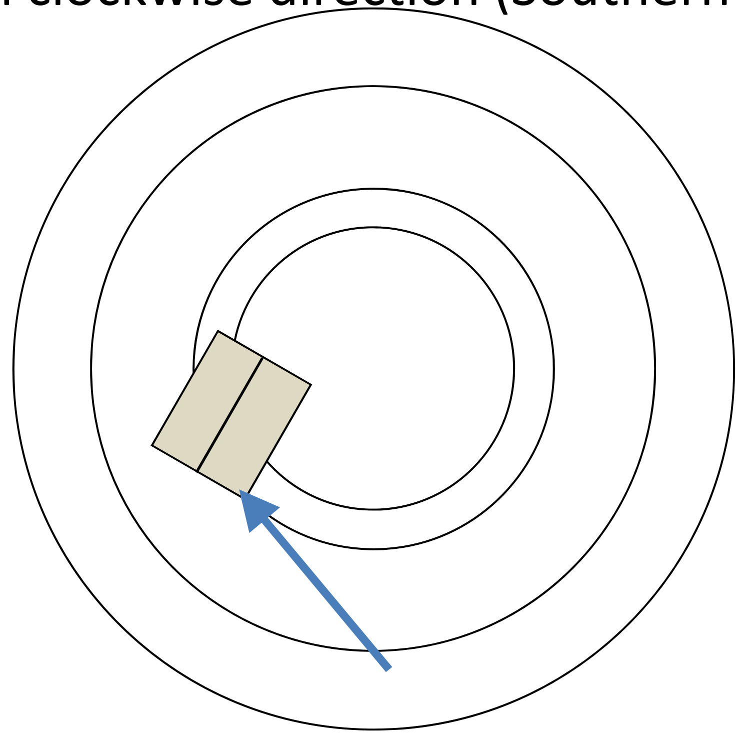
t = 2 hrs

Wind rotation in clockwise direction (Southern hemisphere)



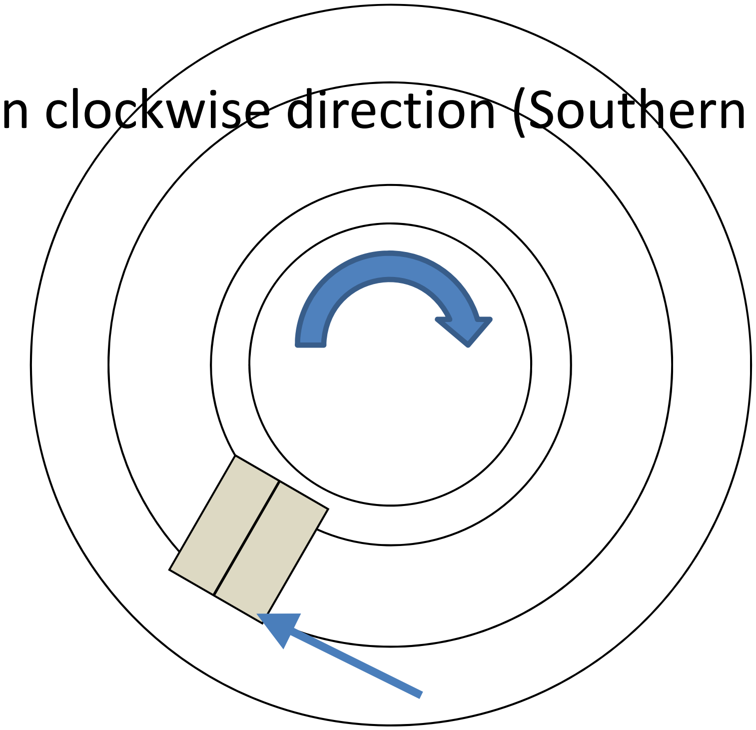
t = 2.5 hrs

Wind rotation in clockwise direction (Southern hemisphere)



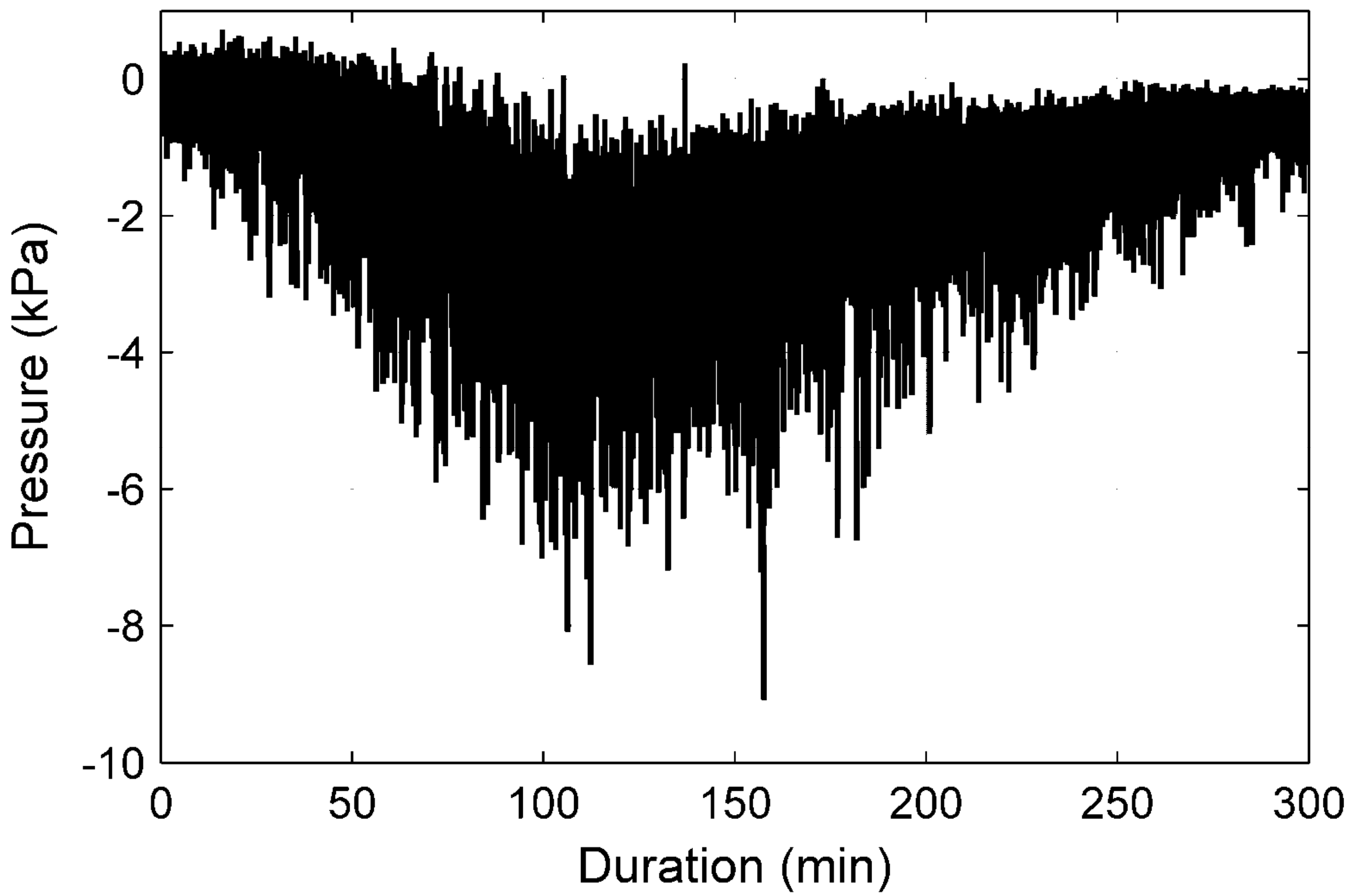
t = 3 hrs

Wind rotation in clockwise direction (Southern hemisphere)



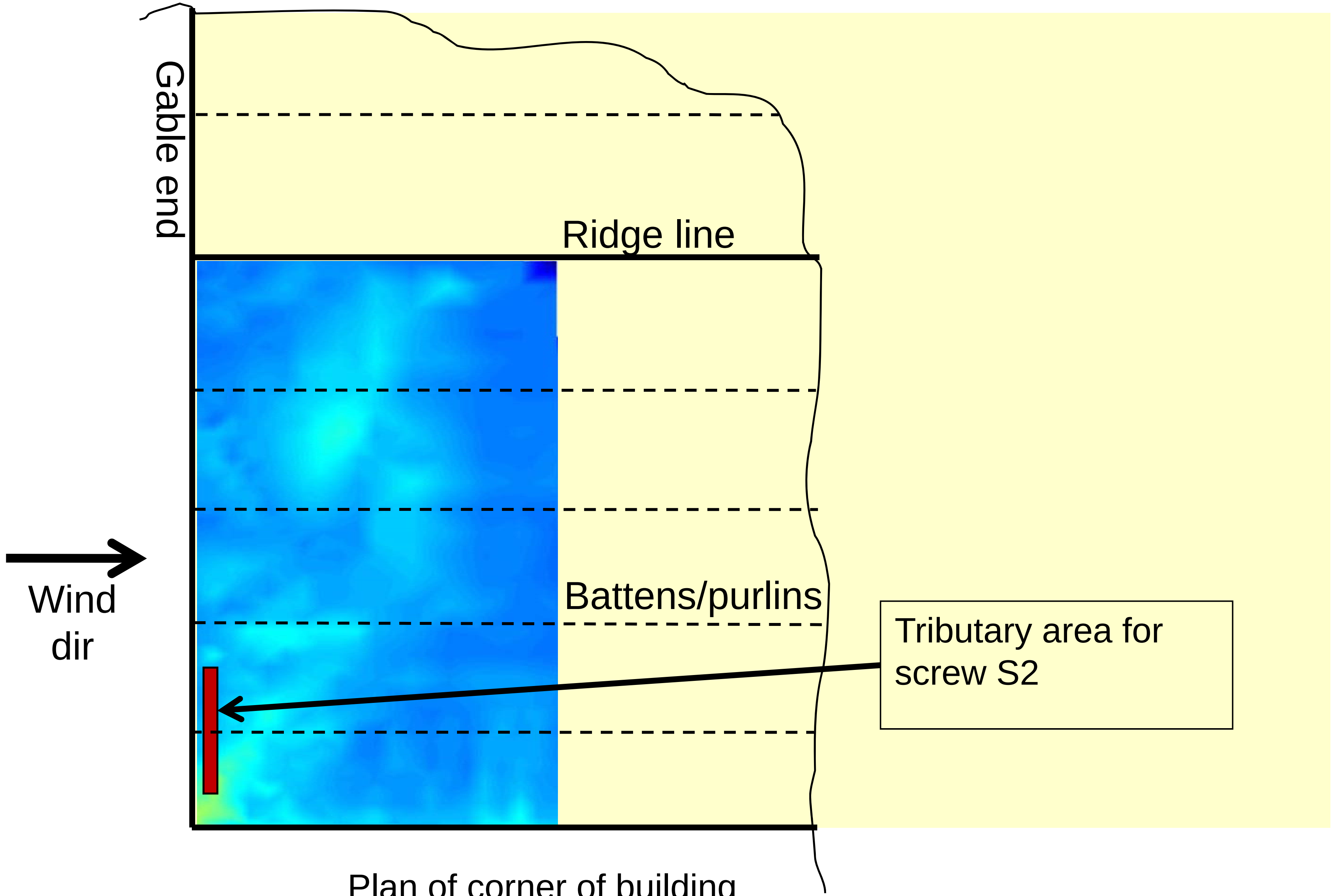
t = 4 hrs

Using the pressure data from the wind tunnel together storm wind speeds and directions…



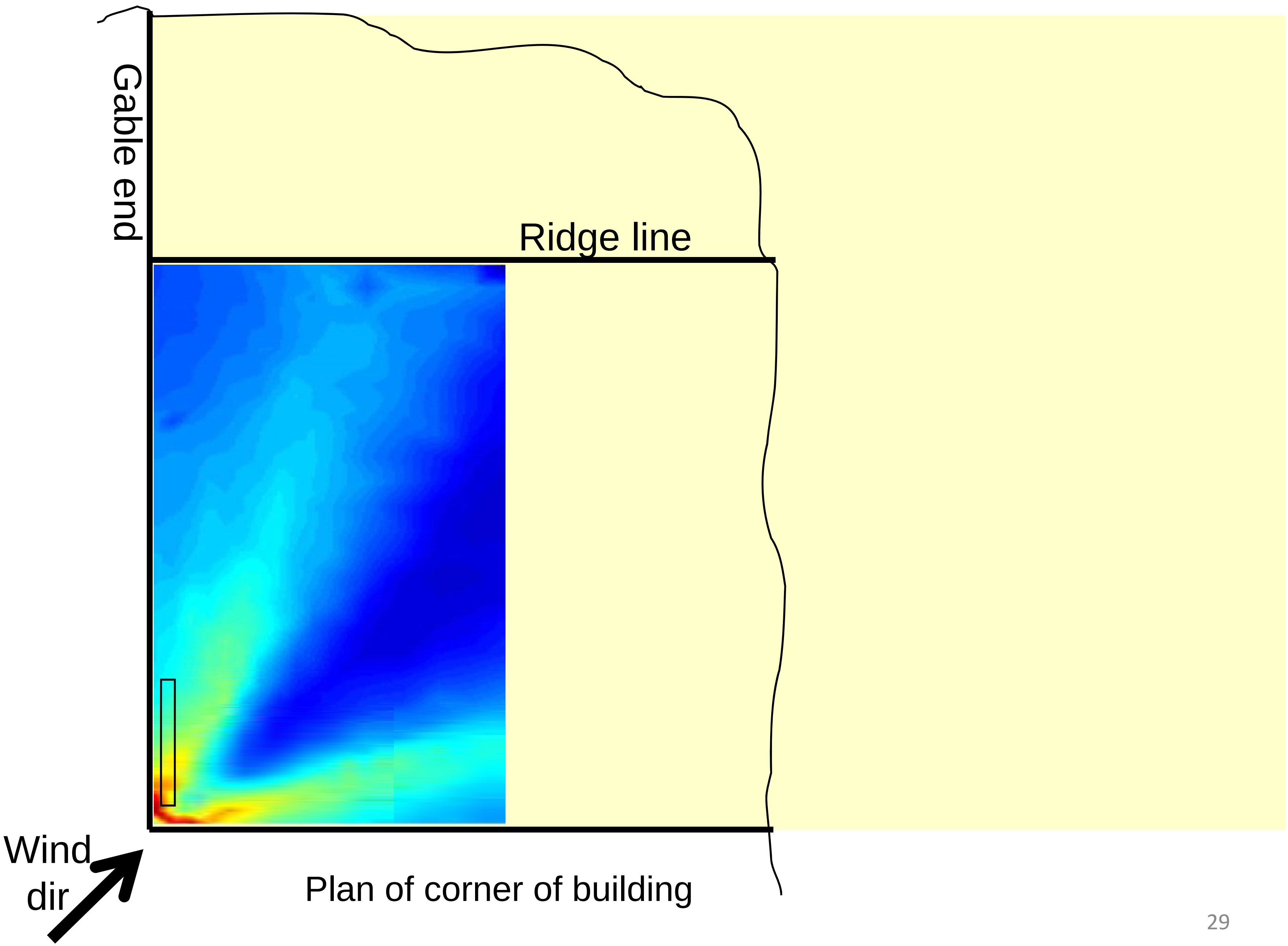
…allows one to pass a hurricane past a building or component in the Lab

Peak pressures (0° wind direction)

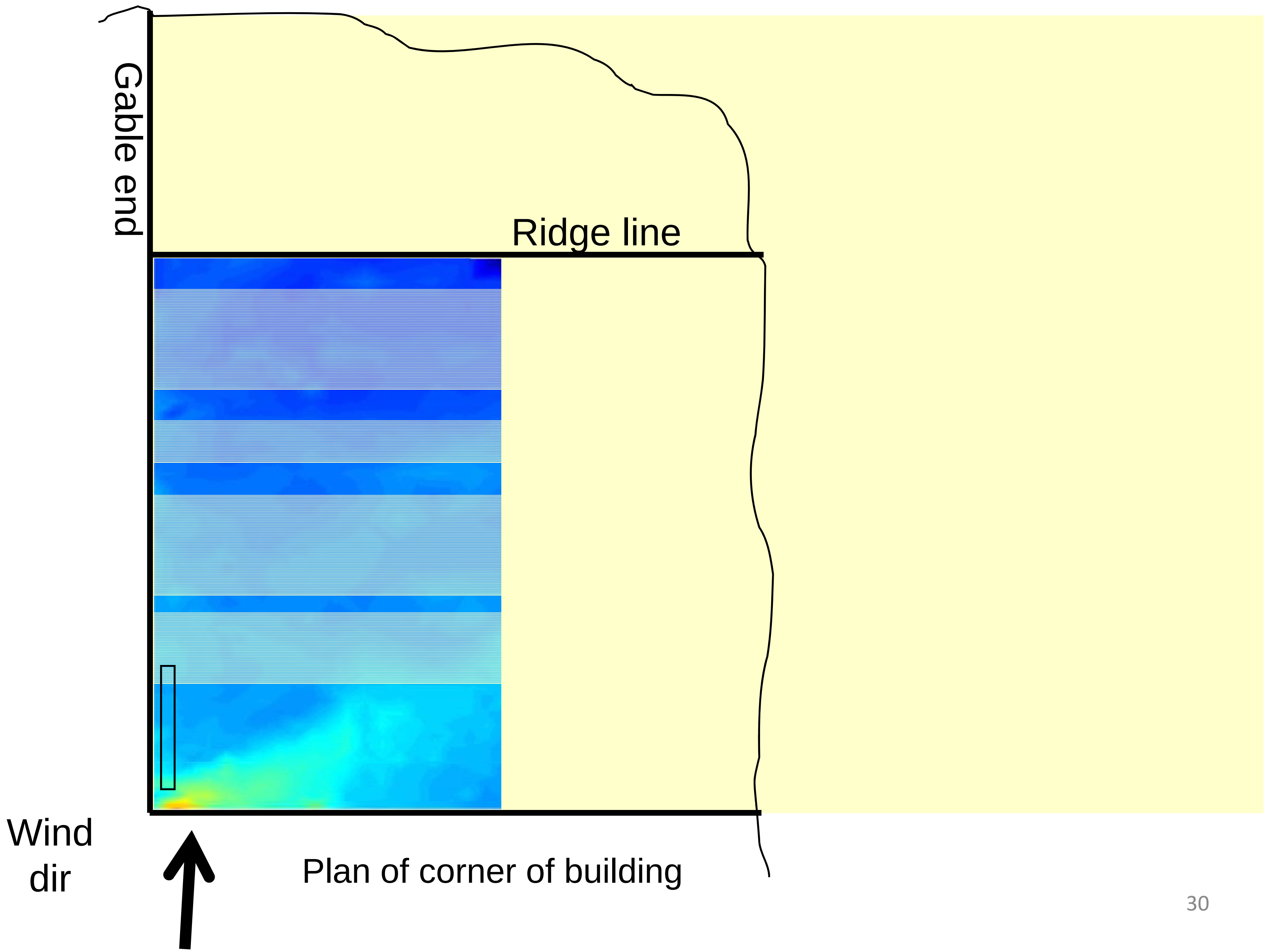


Plan of corner of building

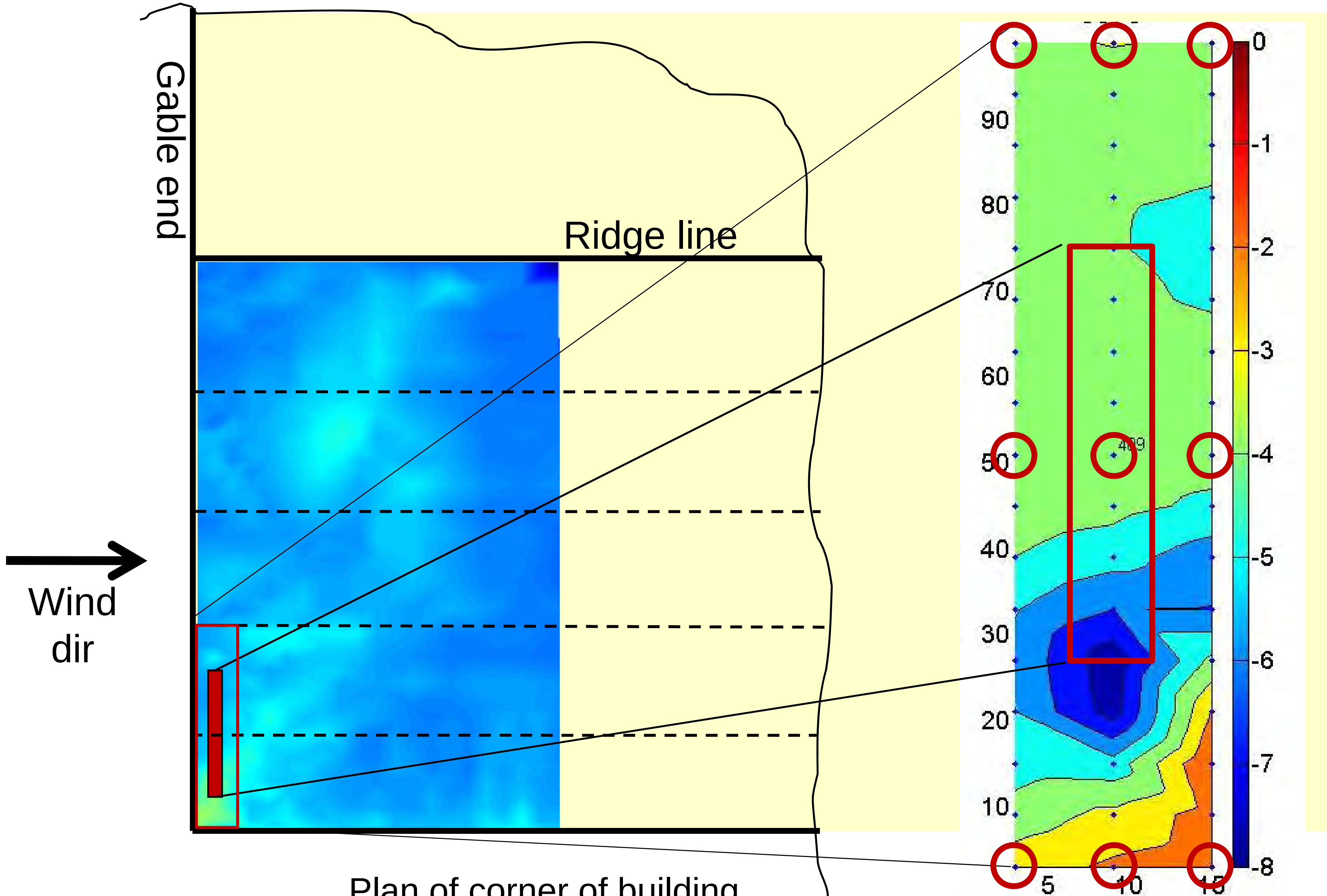
Peak pressures with changing wind direction



Peak pressures with changing wind direction



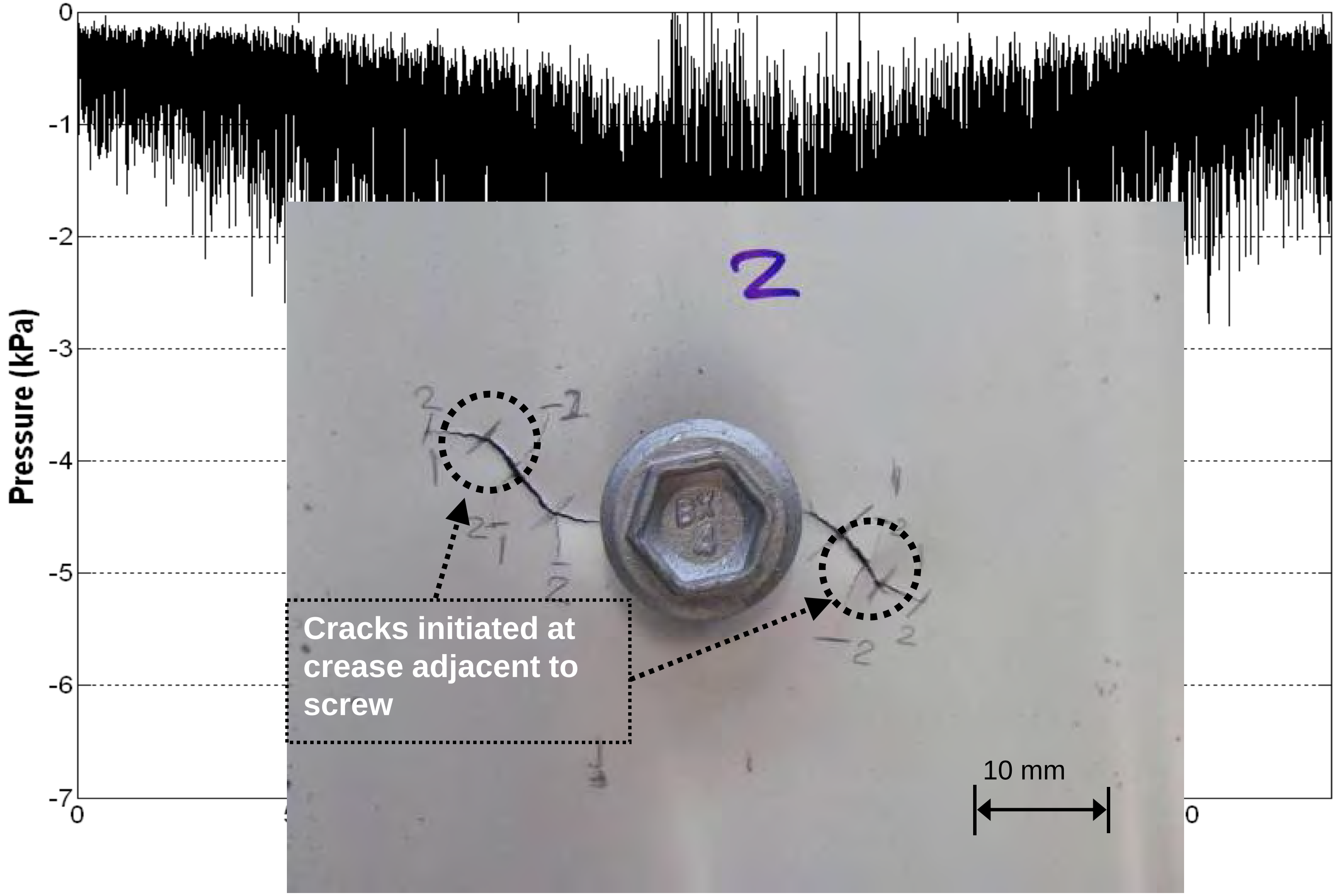
Peak pressures (0° wind direction)



Plan of corner of building

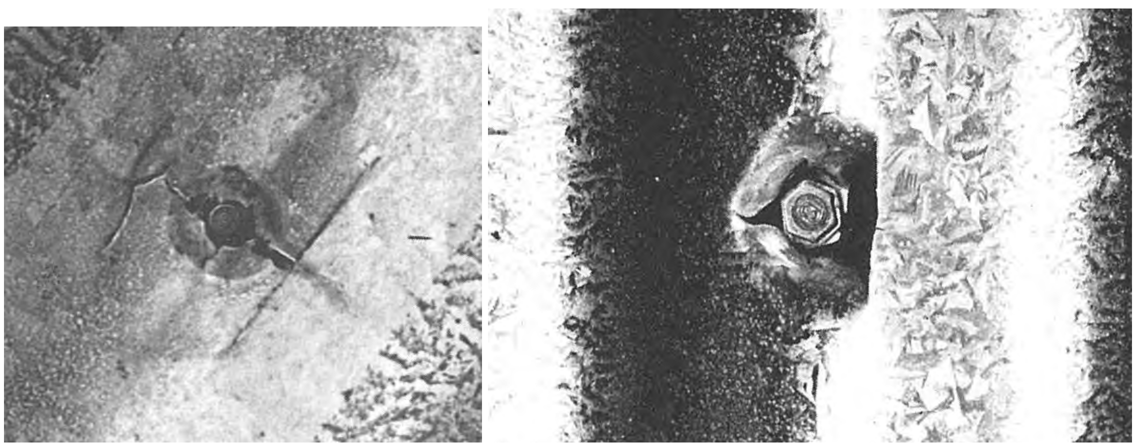
NET pressure trace for "design" cyclone

One example, for low cycle fatigue of metal roofing



Failure of cladding from simulated hurricane

Crack patterns from PLA test



Crack patterns from corrugated cladding after Cyclone Tracy (Beck 1975)

Objectives

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1. Developing new test methods
2. Conducting tests on the various elements which commonly fail

Typical failures observed on houses in extreme wind storms

- Roof sheathing ✔
- Roof structure (complete roof failures) *mostly completed*
- Siding (and wall cladding) *just beginning*
- Wall sheathing ✔
- Windows and glass *just beginning windows; glass completed*
- Roof cover (shingles, tiles on houses, metal roofing and ballasted roofing on commercial buildings)
- Roll-up doors *University of Florida*
- Soffits *University of Florida; completed*
- Rain water penetration through windows and wall assemblies *just beginning*

Typical failures observed on houses in extreme wind storms

- Roof sheathing ✔ *Let's look at this one*
- Roof structure (complete roof failures)
- Siding (and wall cladding)
- Wall sheathing
- Windows and glass
- Roof cover (shingles, tiles on houses, metal roofing and ballasted roofing on commercial buildings)
- Roll-up doors
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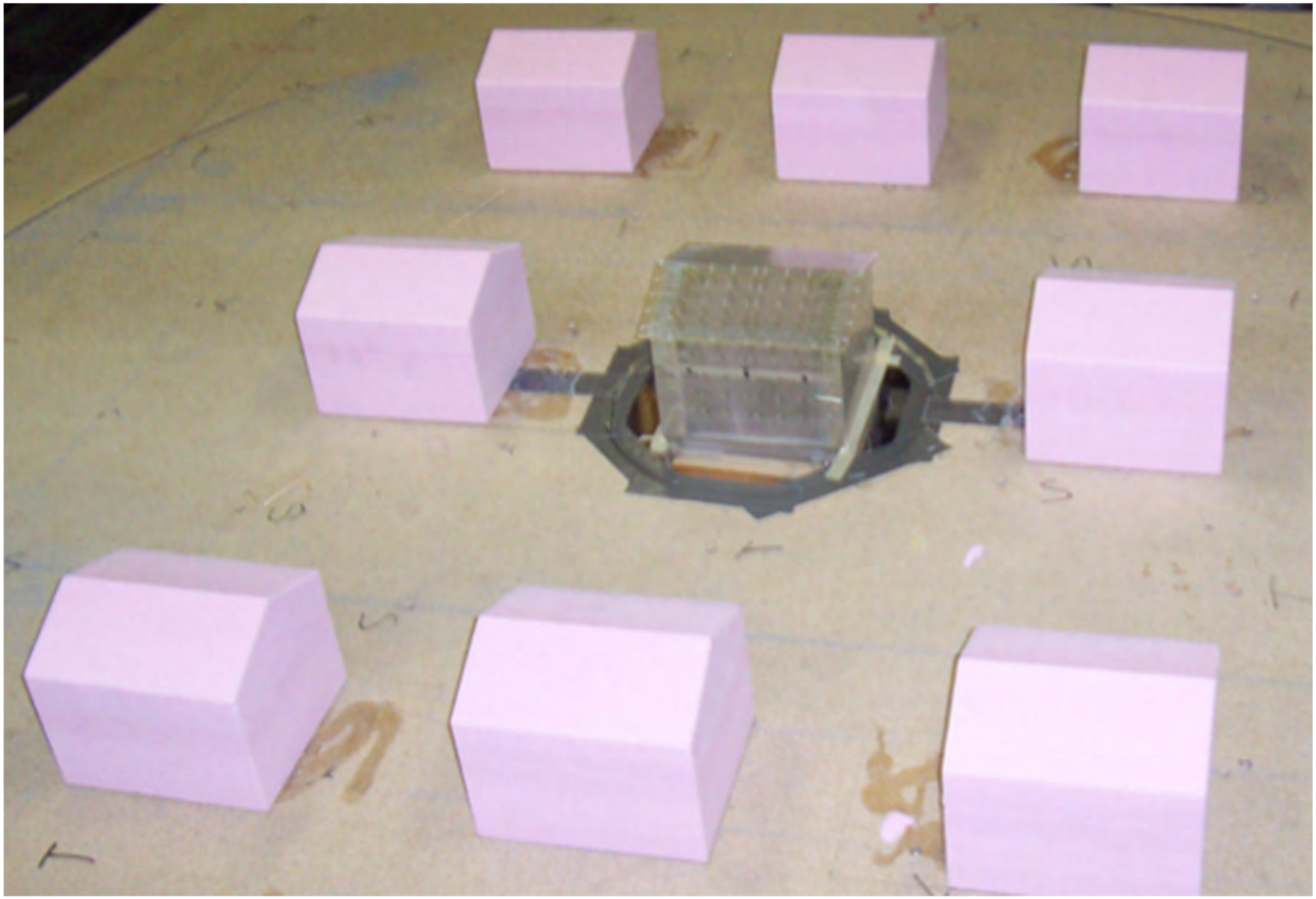
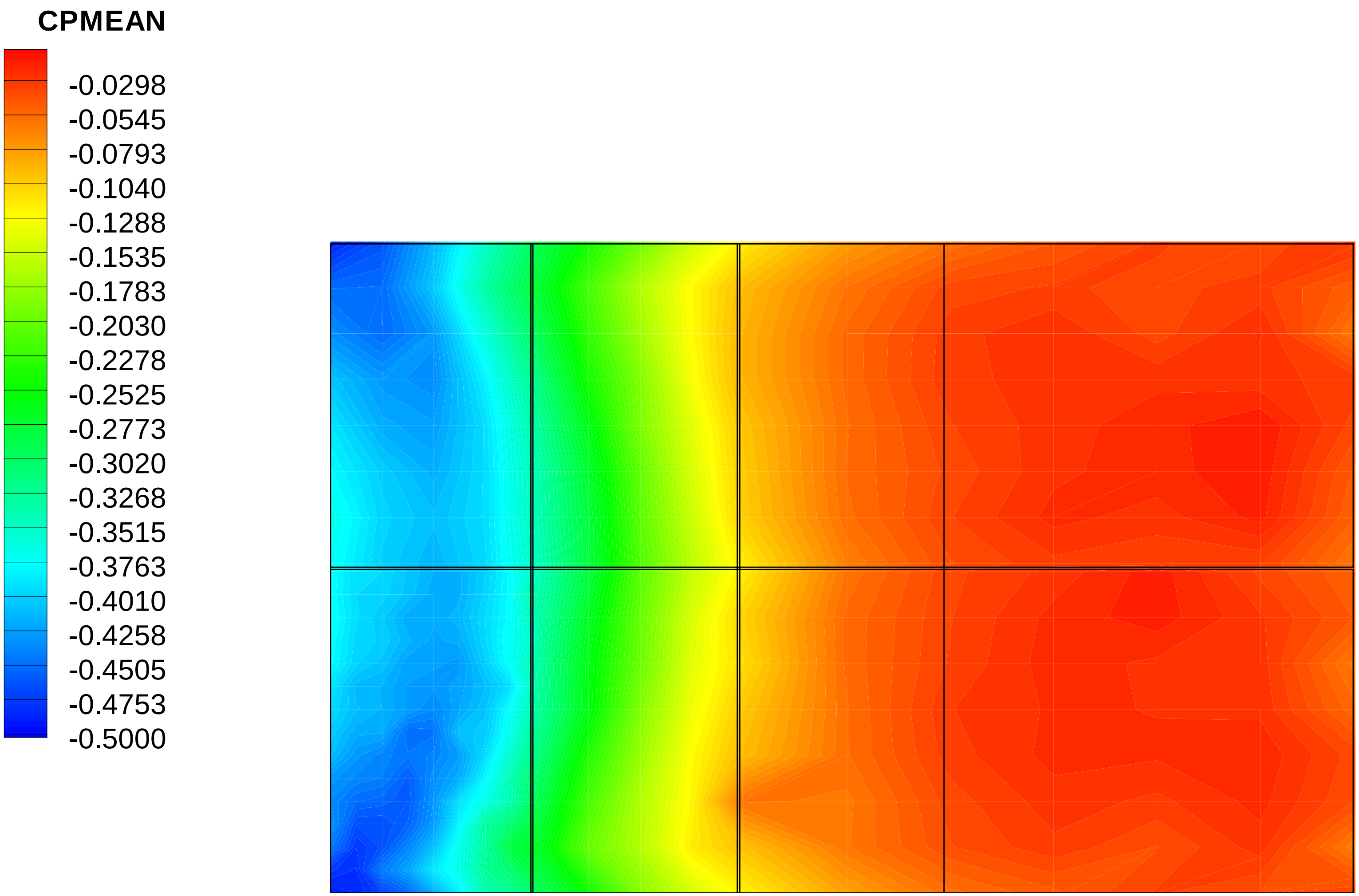
- Rain water penetration through windows and wall assemblies

Wind tunnel study of houses

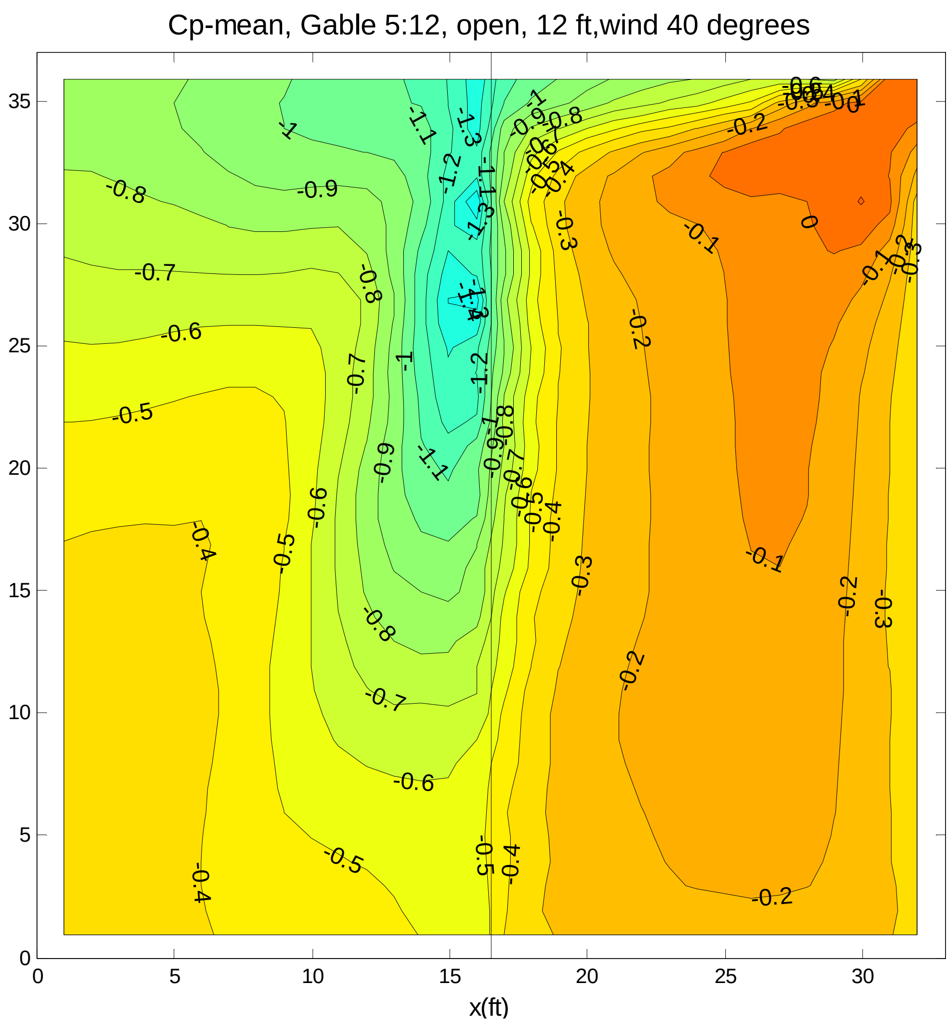


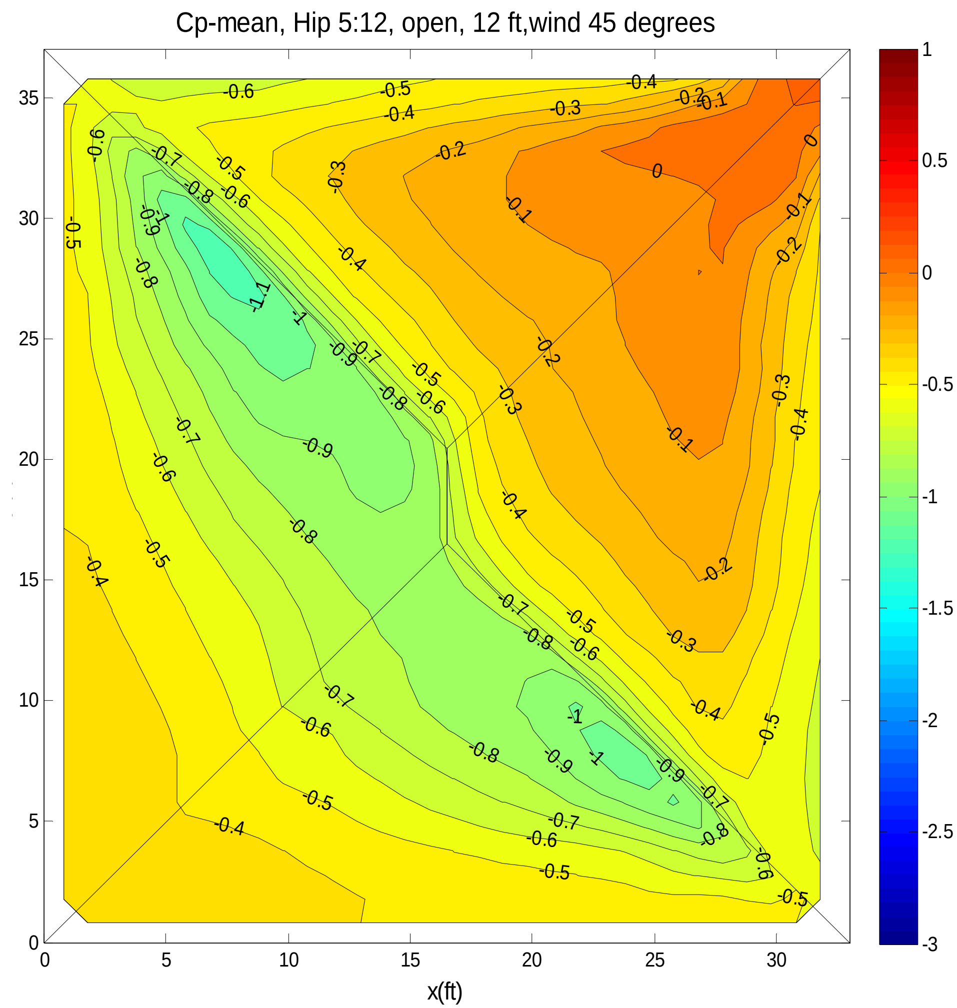
Wind tunnel study of houses

Roof Type	Roof Slope	Roof Dimension (L x W)	Building Eaves Height	Overhang Length	No. of Pressure Taps
Gable	5:12 and 6:12	11.34 m x 10.16 m (37.2' x 33.3')	3.6 m, 6.7 m, 9.1 m (11.7', 22.1', 30') (One-, Two-, Three-storey)	0.46 m (1.5')	230
	7:12, 9:12, and 12:12	11.28 m x 10.06 m (37' x 33')		0.51 m (1.67')	192
Hip	4:12	11.28 m x 10.06 m (37' x 33')		0.51 m (1.67')	592
	5:12 and 6:12	11.34 m x 10.16 m (37.2' x 33.3')		0.46 m (1.5')	242
	7:12, 9:12, and 12:12	11.28 m x 10.06 m (37' x 33')		0.51 m (1.67')	158

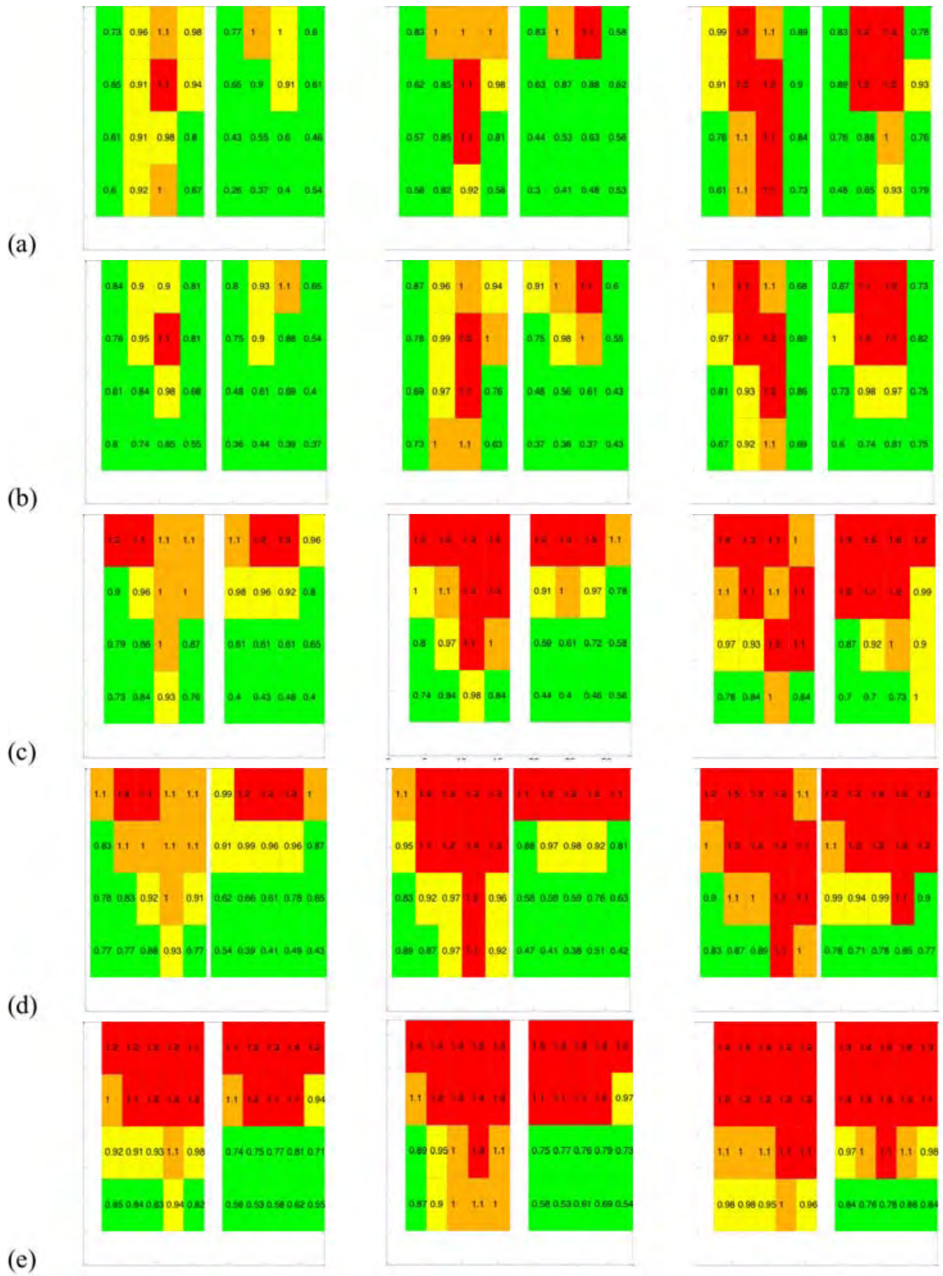

CPMEAN
-0.0298
-0.0545
-0.0793
-0.1040
-0.1288
-0.1535
-0.1783
-0.2030
-0.2278
-0.2525
-0.2773
-0.3020
-0.3268
-0.3515
-0.3763
-0.4010
-0.4258
-0.4505
-0.4753
-0.5000

Gable Roof versus Hip Roof





Ratio of wind tunnel sheathing loads to code values



Ratios for wind directions of 0º-90º to the code (ASCE7-10) load coefficients for:

one storey house in open country (left),

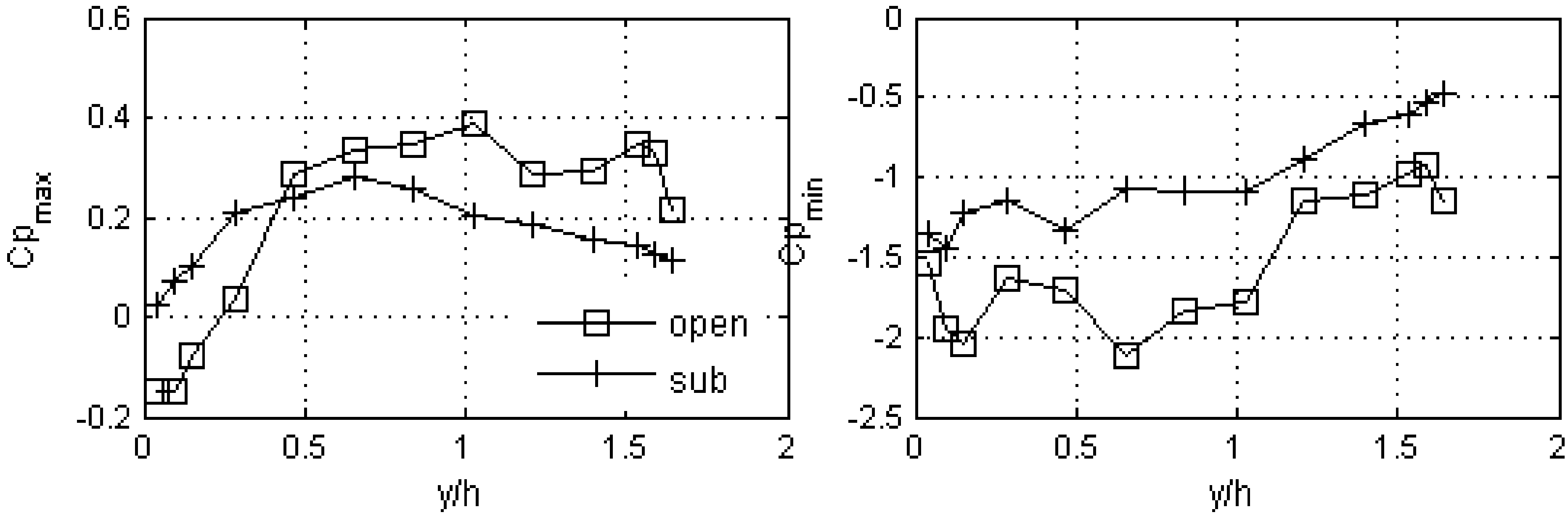
one-storey house in suburban (centre),

three-storey house in open country (right)

with (a) 5:12, (b) 6:12, (c) 7:12, (d) 9:12, and (e) 12:12 gable roof slopes

RED VALUES ARE ABOVE CODE!

For prescriptive codes…we also need to include impact of wind speed and terrain in the coefficients



These are coefficients relative to basic code wind speed. Thus, suburban loads are substantially larger than open country loads.

Table 2 – Fastener Specifications

	Twisted Nail	Ring Shank	Coated Ring Shank Nail	Hurriquake Nail	2 Inch Staple
Length (inches)	2.5	2.5	2.375	2.5	2
Diameter or Gauge (inches)	0.113	0.113	0.113	0.113	0.0625 (16 gauge)
Head Area (inches^2)	0.0483	0.0692	0.0507	0.0779	n/a

Figure 2 – From Left to Right: Twisted Nail, Hurriquake Nail, Adhesive Coated Ring-Shank Nail, Ring-Shank Nail and 2" Staple

Measured Failure Loads for OSB Sheathing

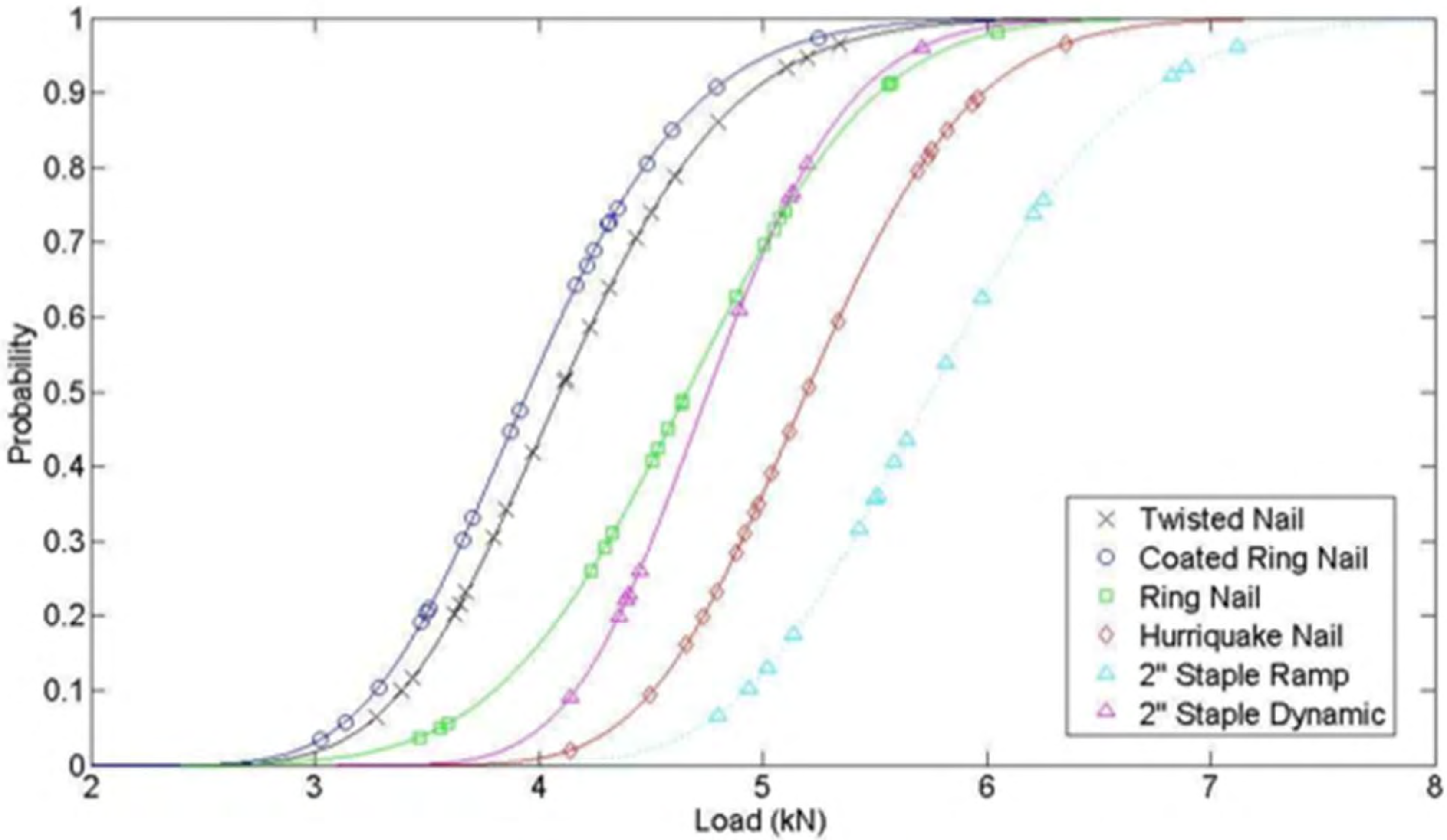


Figure 7 – CDFs of Fastener Failure Capacities

Results, using the ASCE 7-05 with a 2-storey, 4:12 gable roof house in open terrain

OSB	Average Failure Pressure	FOS 1	mph			
			psf	Zone		
				1	2	3
Twist	-4.1	-4.1	-85.6	198	149	113
Ring	-4.7	-4.7	-98.2	212	160	121
Coat ring	-4	-4	-83.5	196	147	112
Hurriq	-5.2	-5.2	-108.6	223	168	128
staple	-4.8	-4.8	-100.3	215	162	123

FOS 2	mph			
	psf	Zone		
		1	2	3
-2.05	-42.8	140	106	80
-2.35	-49.1	150	113	86
-2	-41.8	139	104	79
-2.6	-54.3	158	119	90
-2.4	-50.1	152	114	87

…perhaps not the best solution

DO THE CURRENT FACTORS OF SAFETY ACCOUNT FOR 'ERRORS' IN CONSTRUCTION?

o Lab tests usually yield best possible results on 'perfect' samples. We need to also test for effects of typical errors
oWhen we introduce errors, we get a 10-20mph reduction in the failure wind speed.
o We need to do field studies to examine typical errors for building components. (Some of this could be done in labs.)
o This would allow for probabilistic assessment of capacities of typical construction, when combined with detailed testing (which deliberately introduces errors).

Toe-nail	Mean Failure Capacity (kN)	Standard Deviation (kN)	#split / #pull outs
No Defect	2.8	0.6	22/41
Defect #1	1.9	0.46	11/5
Defect #2	2.2	0.48	0/16

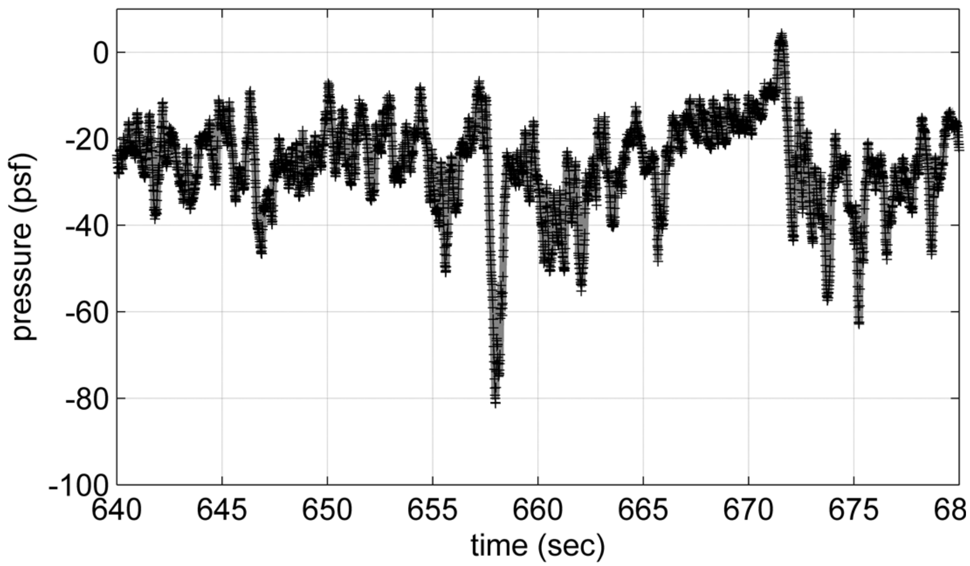
CAN WE RETRO-FIT RESIDENTIAL ROOFS INEXPENSIVELY?

- Our results show load sharing is significant at failure. If we can stiffen the roof inexpensively, and use a handful of hurricane straps, this will enhance help us take advantage of poorly correlated roof loads.

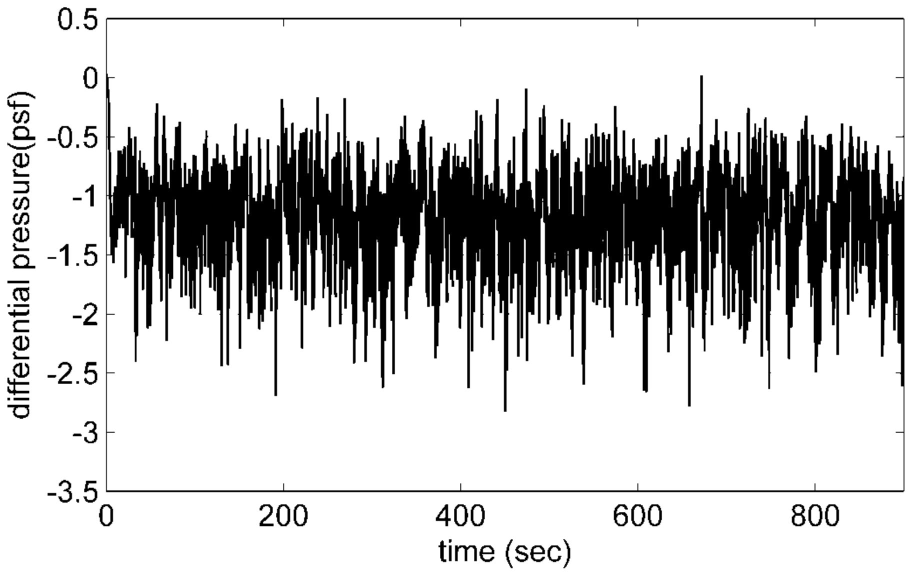
- We are investigating effects of roof stiffness now if order to develop a simple model for the role of this parameter.

PRESSURE EQUALIZATION AND SIDING FAILURES

- Our wall sheathing study has shown that pressure equalization – a mechanism to share loads across different layers in the building envelope – is critical to performance in extreme winds.
- When we allow pressure equalization by utilizing multi-layer wall systems, the exterior sheathing does not fail (for maximum hurricane wind speeds). Thus, this is a method to further mitigate wind effects.
- A detailed study to develop a model for this is underway.



External Pressure



Differential Pressure

Closing Remarks

Our full-scale testing methods, combined with damage surveys following storms, and traditional wind tunnel studies allow us to examine the effects of extreme winds in a realistic way, to answer many questions with much more precision than previously possible.

This is aiding us in developing understanding of the basic mechanics, and engineering models, for the range of different loading issues and failure issues.

All major issues pertaining to residential construction are being examined.

Results are being used to (i) modify building codes and design practice, (ii) "calibrate" the Fujita Scale for tornado damage, (iii) develop engineering and mechanistic models for a range of purposes including risk/loss models.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