NSF NHERI

WALL OF WIND

EXPERIMENTAL FACILITY

FIU | Wall of Wind

NHERI Experimental Facility

NHERI enables research and educational advances that can contribute knowledge and innovation for the nation's civil infrastructure and communities to prevent natural hazard events from becoming societal disasters.

Contents

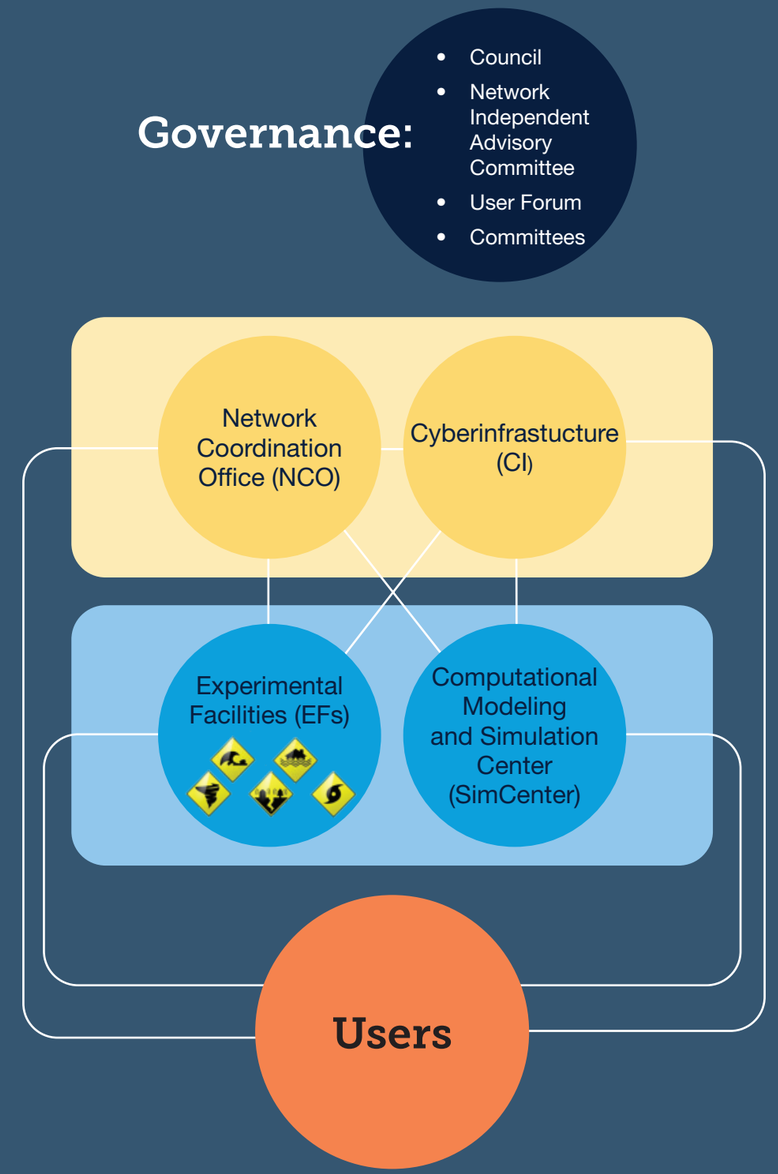
Natural Hazards Engineering Research Infrastructure

Natural Hazards Engineering Research Infrastructure (NHERI) is a distributed, multi-user, national facility that provides the natural hazards engineering community with access to research infrastructure (earthquake and wind engineering experimental facilities, cyberinfrastructure, computational modeling and simulation tools, and research data), coupled with education and community outreach activities.

NHERI consists of the following components, established through eleven individual awards:

- Network Coordination Office (NCO: Purdue University)
- Cyberinfrastructure (CI: University of Texas at Austin)
- Computational Modeling and Simulation Center (SimCenter: University of California-Berkeley), and
- Experimental Facilities for earthquake engineering and wind engineering research:
    - Florida International University: Wall of Wind (WOW)
    - Lehigh University: Advanced Technology for Large Structural Systems (ATLSS)
    - Oregon State University: O.H. Hinsdale Wave Research Laboratory
    - University of California, Davis: Center for Geotechnical Modeling (CGM)
    - University of California, San Diego: Large High Performance Outdoor Shake Table (LHPOST)
    - University of Florida: Powell Family Structures and Materials Laboratory
    - University of Texas at Austin: Dynamic in-situ testing using large-scale mobile shakers
    - University of Washington: Post-disaster, Rapid Response Research Facility (RAPID)

The primary research enabled by NHERI is conducted by investigators supported through separate National Science Foundation (NSF) awards. The Awardees and the natural hazards engineering community work together, through Governance and Awardee activities, to establish a shared vision for NHERI, set natural hazards engineering research and education agendas and priorities, and make NHERI a value-added and productive research infrastructure. Visit www.designsafe-ci.org for more information on NHERI and its components.



NHERI Wall of Wind Experimental Facility

The NHERI Wall of Wind (WOW) Experimental Facility (EF) at Florida International University (FIU) was funded by NSF to be a national facility that enables researchers better understand wind effects on civil infrastructure systems and prevent wind hazards from becoming community disasters. The NHERI WOW EF is powered by a combined 12-fan system capable of repeatable testing in up to 157 mph wind speeds through its flow management system. The unique advantage of the NHERI WOW EF is multi-scale (full-scale to 1:400) and high Reynolds number simulation of the effects of wind and wind driven rain. This is accomplished using the twelve fans and a water spray system. In addition, the 16,000 sqft. fenced-off secure area enables researchers to plan and perform destructive tests under up to Category 5 Hurricane wind speeds. The NHERI WOW EF offers users a wide range of equipment, instrumentation and experimental simulation protocols as well as a distinguished group of faculty staff and a well-trained team of technical and operations staffs which allow for delivering world-class research.

OUR SCIENTIFIC VISION

To enable frontier research and education to impart resiliency and sustainability to new and existing buildings, cladding systems, and lifeline infrastructure, to prevent wind hazards from becoming community disasters.

The NHERI WOW EF provides the following experimental capabilities:

- High-speed holistic testing at multiple scales in simulated hurricane wind speeds up to and including Category 5 Hurricane on the Saffir-Simpson scale
- Destructive tests to study failure modes
- Wind-driven rain simulations to study water intrusion
- Full- and large-scale aerodynamic/aeroelastic testing in atmospheric boundary layer (ABL) flows at high Reynolds numbers
- Testing under extreme environments to develop innovative mitigation devices
- Conventional boundary layer wind tunnel testing in flows with various exposures and with full turbulence spectrum

Research topics that can be investigated at the NHERI WOW EF include (but are not limited to):

- Obtaining wind load data for a wide range of building shapes, accounting for interference and shielding effects not addressed in current design standards. The archived database can help researchers study peak loads and validate computational methods
- Holistic testing of integrated component assemblies to determine fragilities, progressive failure modes, and wind driven rain intrusion mechanisms
- Validating sustainable building concepts and innovative mitigation strategies
- Developing more energy efficient and smart building envelopes, identifying on-site renewable energy sources, and implementing natural ventilation strategies
- Through strategic partnerships, investigating the use of aerodynamic data from straight winds in designs for tornadoes and downbursts

Meet the Team

The NHERI WOW EF team consists of a distinguished group of faculty and highly educated and well-trained operations and technical staff which enable delivering outstanding research.

Roles and responsibilities:

Arindam Chowdhury
Leadership
Leads scientific and operational vision; facilitates education/outreach; serves on Council

Peter Irwin
Leadership
Addresses research challenges in Science Plan; helps achieve operational goals

Ioannis Zisis
Leadership
Oversees EF's key deliverables/milestones; leads performance assessment

Laird Kramer
Leadership
Leads the education/outreach program; helps the PI with active learning modules/teacher training

Amal Elawady
Leadership
Implements and pursues cooperation with EF collaborators to fulfill the plans

Maryam Refan
Management
Manages EF project planning and staff efforts; coordinates with NCO/Users; broadens EF user base

Walter Conklin
Management
Performs EF maintenance; ensures EH&S compliance; provides user safety training

Roy Liu Marques
Operations
Facilitates EF experiments, data acquisition, and data quality assurance

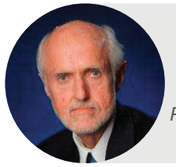
Raphael Greenbaum
Operations
Implements cyberinfrastructure and facilitates cybersecurity; develops software; calibrates instruments

Ashkan Rasouli
Operations
Implements test protocols; facilitates experiments; ensures data quality; performs data processing

Bodhisatta Hajra
Research
Performs data processing; prepares reports and publishes research findings

Laird Kramer, PhD
STEM Education and Outreach
Professor

Walter Conklin
Laboratory and EH&S Manager



Peter Irwin, PhD
Co-PI
Professor of Practice

Roy Liu Marques
Project Engineer

Arindam Chowdhury, PhD
Director and PI
Associate Professor

Maryam Refan, PhD
Site Operations Manager

Raphael Greenbaum, PhD
Research Specialist

Ioannis Zisis, PhD
Co-PI
Assistant Professor

Ashkan Rasouli, PhD
Research Specialist

Amal Elawady
Assistant Professor

Bodhisatta Hajra, PhD
Research Scientist

Services We Provide

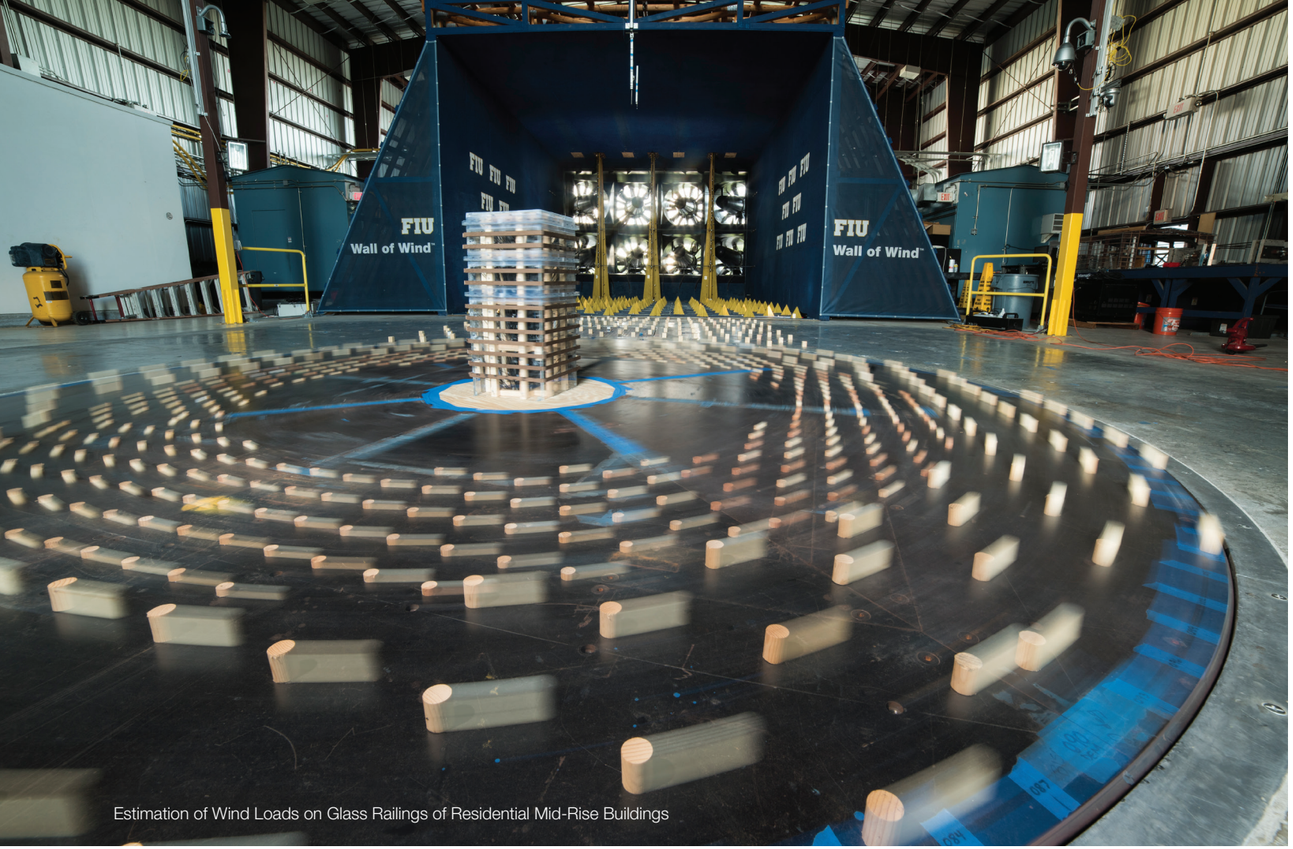
The services provided by the NHERI WOW EF to the users include:

- Support for NSF proposal development
- Design, construction, instrumentation of test specimens
- Test protocols and software implementation
- Operations of the wind tunnel
- Data acquisition, archiving and curation
- Processing and post processing of the data (depending on the proposal)
- User training and safety
- Telepresence for remote participation
- Outreach and dissemination
- Office space and internet service for users during their visit

NHERI Wall of Wind EF Usage Rates

The following table provides the rates associated with NHERI projects only. NHERI projects are defined as projects receiving funding from NSF to utilize the NHERI Wall of Wind Experimental Facility. All other, non-NHERI, projects are subject to regular recharge center rates.

SERVICE DESCRIPTION	UNIT	NHERI USERS RATE
Pre-testing Setup	Day	$370
Running-time	Day	$1,810
Post-testing	Day	$339



Estimation of Wind Loads on Glass Railings of Residential Mid-Rise Buildings

Facility and Instruments Portfolio

Facility: Wall of Wind (WOW)

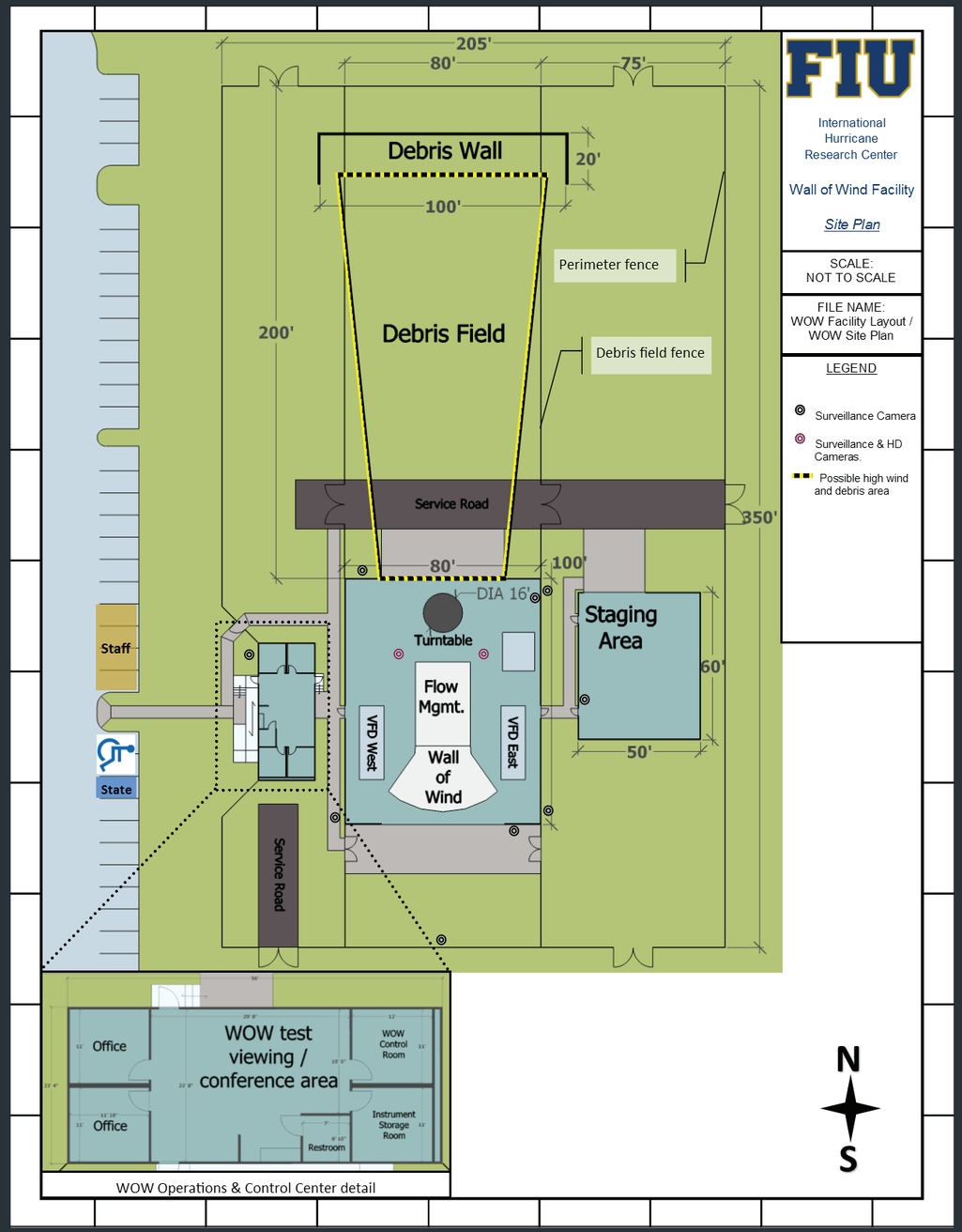
- Open jet large wind tunnel
- 12 electric fans in an arc-focal arrangement
- Wind field cross-sectional area of 20ft (6.1m) W x 14ft (4.3m) H
- Wind speed range of 10mph (16 km/hr) – 157mph (253 km/hr)
- Open, Suburban and Uniform exposures
- 16ft (4.9m) diameter turn table
- Turn table capacity of 105,000lb (47.6 tons) static / 52,000lb (23.6 tons) dynamic
- Rotational speed range of 0.015-0.0014min/deg

Instruments

The NHERI WOW EF has instruments to quantify the wind field as well as the wind-induced effects on structures and components. Some of the most commonly used instruments are listed below.

INSTRUMENTS	TYPE OF MEASUREMENTS
Cobra probes	Wind speed and turbulence
Uni-axial load cells	Force
JR3 tri-axial load cells	6-DOF forces and moments
Strain gauges	Strain
Pressure scanners	Differential pressure
Accelerometers	Triaxial acceleration
String potentiometers	Displacement
LVDT	Displacement
Laser displacement sensors	Displacement
Tri-axial inertial sensors	Tri-axial accelerometer, magnetometer and gyroscope,temperature sensor and pressure altimeter
Parsivel² laser disdrometers	Size and speed of precipitation
Rain measurement gauges	Wind-driven rain rate and rainwater deposition
Weather sensors	Temperature and humidity
Smoke generator	Flow visualization
HD and surveillance cameras	Test monitoring and telepresence

Site Plan



Recently Funded NSF Projects Using NHERI WOW EF

Title: Experimentally Validated Stochastic Numerical Framework to Generate Multi-Dimensional Fragilities for Hurricane Resilience Enhancement of Transmission Systems

PI: Abdollah Shafieezadeh, Ohio State University

NSF Program: Engineering for Natural Hazard (ENH)

Summary: This research will produce a state-of-the-art experimentally validated stochastic numerical framework to generate multi-dimensional fragility models for hurricane resilience enhancement of transmission systems. The research will involve a series of aeroelastic wind tunnel studies on the wind response of multi-span transmission systems at the NHERI Wall of Wind EF at FIU. These novel sets of experimental data, together with high-fidelity three-dimensional nonlinear finite element models of tower-conductor-insulator-foundation systems, will provide new and critical insights into various complex wind-induced behaviors of these systems. The WOW tests will also enable characterization of dynamic boundary effects from neighboring spans. The multi-dimensional fragility surfaces, based on validated numerical models, will provide component- and system-level structural and functional failure probabilities for units of transmission tower-lines.

Title: Uncovering Potential Risks of Wind-induced Cascading Damages to Construction Projects and Neighboring Communities

PI: Youngjib Ham, Florida International University

NSF Program: Civil Infrastructure Systems (CIS)

Summary: Using knowledge on potential at-risk construction resources obtained through experimental testing of extreme wind events, this project will partially or fully automatically model the current state of construction sites through machine vision techniques using multimodal visual data obtained from construction workers and camera-equipped unmanned aerial vehicles. To perform multi-physics simulation of multiple discrete objects in unstructured construction sites, an impulse-based discrete element method will be conceptualized. Component-based vulnerability and impact analysis with 3D Building or Civil Information Models (BIM/CIMs) will then be conducted to generate fundamental and highly specific knowledge on wind-induced damage mechanisms. Finally, the entire system will be validated in real-world construction projects and within a 12-fan NHERI Wall of Wind facility that can generate up to hurricane category 5 wind speeds.

Title: Pervasive Spectrum Sharing for Public Safety Communications

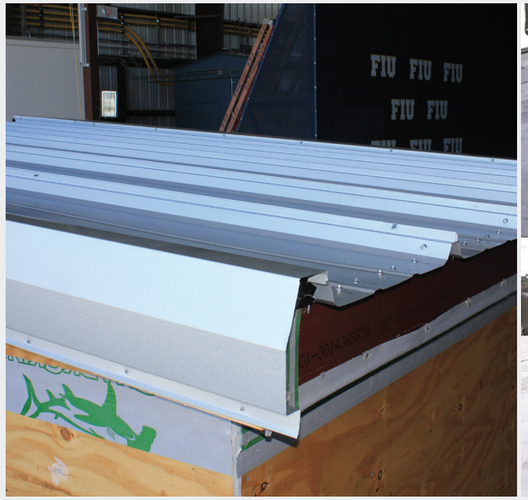
PI: Kemal Akkaya, Florida International University

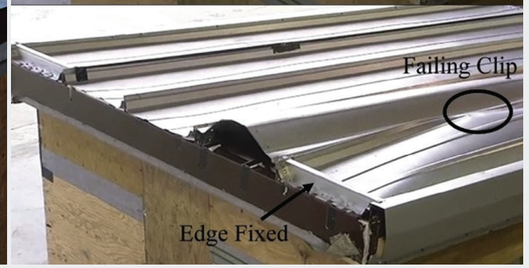
NSF Program: Enhancing Access to the Radio Spectrum (EARS)

Summary: This project tackles multidisciplinary challenges by involving several departments, Civil, Computer Science, Electrical, Public Administration, and Mathematics and Statistics, from four universities. The project goal is to create next-generation public safety communication (PSC) systems to deliver high-capacity wireless services to public safety personnel and users in disaster-affected areas. The new PSC systems development, aided by estimates of higher-frequency signal attenuation (at higher frequencies) in hurricane wind and rain scenarios simulated at the NHERI Wall of Wind EF, will expedite the response to disasters, save lives, and reduce economic impacts. This project highlights how the NHERI Wall of Wind EF can facilitate wind-related collaborative research that transcends the traditional boundaries of civil and structural engineering.

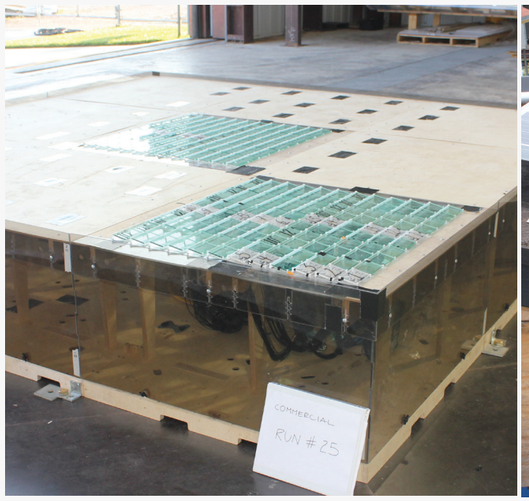
Examples of Research Capabilities

Topic: **Standing seam metal roof**
Measurement type: Full-scale, Internal and external pressure and Deflection
Instrument(s): Pressure scanner, LVDT and String potentiometer

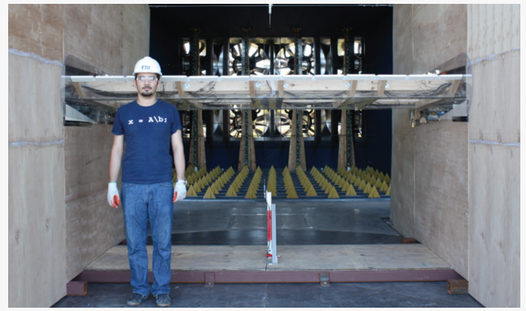




Topic: **Photovoltaic systems**
Measurement type: Full-scale and large-scale (1:20), Pressure aerodynamic force
Instrument(s): Pressure scanner and Tri-axial load cell



Topic: **Long span bridge aerodynamics**
Measurement type: 1:36 Sectional, Surface pressure and Aerodynamic force
Instrument(s): Pressure scanner and Tri-axial load cell

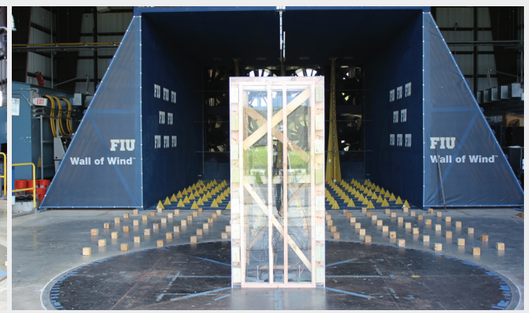


Topic: **Roof pavers**
Measurement type: Large-scale (1:2), Wind blow-off and Surface pressure
Instrument(s): Pressure scanner

Topic: **Rain deposition on low-rise buildings and rain intrusion studies**
Measurement type: Full-scale and large-scale (1:4), Wind driven rain deposition (RAF and SRC)
Instrument(s): Parsivel² laser disdrometer and Rain measurement gauge

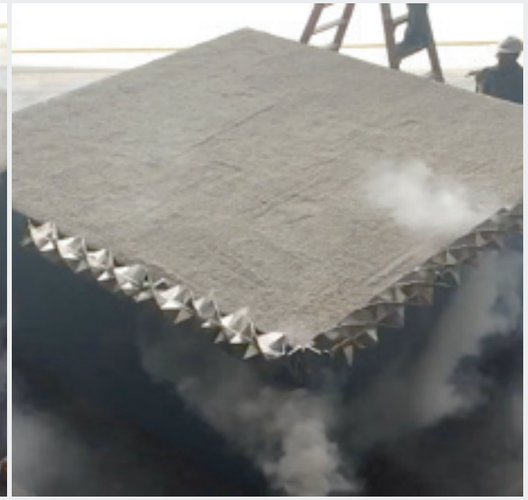
Topic: **Estimation of wind loads on glass railings of residential mid-rise buildings**
Measurement type: Large scale (1:67), Surface pressure
Instrument(s): Pressure scanner

Topic: **Investigation of scaling effects**
Measurement type: Multi-scale (1:25,1:67,1:180), Surface pressure
Instrument(s): Pressure scanner



Topic: **Wind induced dynamic and aeroelastic effects on traffic signs and signals**
Measurement type: Full- and large-scale (1:3), Wind induced loads, Accelerations and Inclinations
Instrument(s): Tri-axial load cell, Accelerometer and Inclinometer

Topic: **Aerodynamic mitigation and power generation using building integrated wind turbine**
Measurement type: Large-scale (1:6.5), Surface pressure and Flow visualization
Instrument(s): Pressure scanner and Smoke generator
Patented: US 2015/0345472 A1



Topic: **Progressive failure study for residential structures to validate FEMs**
Measurement type: Large-scale (1:4), Surface pressure, Strains and Deflections
Instrument(s): Pressure scanner, Strain gages, LVDT and String potentiometers

Experimental Protocol

The Wall of Wind Experimental Facility allows NHERI users to generate new and highly specific knowledge on wind loading, wind damage and rain intrusion mechanisms. The goal is to improve design practices and create more wind-resilient and sustainable communities.

The standard experimental protocols and specifications for EF-enabled user projects outline the scope, objectives, test specimen design, scaling (length, velocity and time scales), instrumentation, wind parameters, rain parameters (if applicable), test duration, data sampling rate, and safety procedures.

Physical Measurement Test Protocol

Pertains to obtaining quantitative aerodynamic and aeroelastic data before any failure occurs. Typically, valuable information is collected at lower wind speeds, where the risk of damaging the test model and/or instrumentation is lower. The protocol describes terrain roughness, wind speed increments, test duration, range of wind directions, time intervals between runs, and other test-specific parameters. The protocol is complemented by the available Standard Operating Protocols (SOP) for each instrument measuring wind-induced effects.

Failure Mode Test Protocol

Pertains to holistic system-level testing up to failure. Wind speed is incrementally increased to the maximum possible value to study failure modes, if failure occurs. The instrumentation applicable to this type of experiment is less comprehensive and is mainly focused on vibration measurements. In most of the cases, the instrumentation should be removed when imminent failure is observed or while testing at the highest wind speeds. The protocol describes general parameters (as in Physical Measurement Test Protocol) and delineates procedures for video recording of damage initiation, progressive damage propagation, failure modes, and rainwater intrusion mechanisms.

Wind-Driven Rain Test Protocol

Describes specimen preparation and procedures for tests under wind-driven rain. Nozzle types, spacing, and arrangement are specified for achieving target rain drop size distribution and rain intensity. Moisture sensors and rain collection systems and their locations in test models to detect and measure quantity and pattern of water intrusion are also specified.

Payload Project Protocol

The NHERI Wall of Wind (WOW) EF team has developed a procedure that allows integration of payload projects in main NHERI WOW EF Projects. This procedure effectively communicates the specific requirements for wind engineering projects as well as the unique specifications of the NHERI WOW EF and its instrumentation. The NHERI WOW EF has also developed a questionnaire that potential payload project users complete before they proceed with their proposal submission to NSF. This Payload Project Questionnaire, will serve as the contact form between the payload project principal investigator (PI) and the main NSF project PI (if no contact has been established yet). The payload project procedure is facilitated through various protocols as follows:

Schedule of upcoming projects

The NHERI WOW EF, in coordination with NCO, will create a calendar of scheduled projects which will be available at the DesignSafe-CI website. For each of the main NHERI WOW EF projects the following information will be included: scope of work, anticipated timeline, overview of the testing apparatus, model characteristics, instrumentation and testing protocol (e.g. sensors, wind speeds, wind directions, etc.).

Available payload area

For wind engineering applications, the concept of payload area is differently defined from the existing seismic payload projects. Altering the main project's test model geometry, structural system or surroundings may conflict with the objectives of the main project. Therefore, the concept of available payload area should be described by the main NSF project PI (in the Service Agreement) as availability for non-interfering model modifications or an addition of instrumentation. The payload project PI will need to mention any need for significant modifications in the NHERI WOW EF Payload Questionnaire and discuss the feasibility of its research concept with the main NSF project PI.

Payload project technical information

The payload project proposer will need to furnish the following information to the main NSF project PI and the NHERI WOW EF team: scope of work summary, safety plan covering all safety concerns and mitigation methods, testing objectives, specification of required instrumentation, data acquisition settings for each group of sensors, testing protocol and testing configurations. This will help the payload proposer to gain technical approval of the project.

Payload Project Timeline

In conjunction with the main NSF project PI and the NCO, the NHERI WOW EF will develop a timeline for each NSF funded user project which will include the plan of activities with regards to the model construction, instrumentation installation and testing dates. For each of these activities there will be a cutoff date after which payload requests may not be possible to be accommodated. As far as the payload project is concerned, the NCO, in coordination with the NHERI WOW EF, will provide a detailed list of milestones and dates that will serve as a guide to the payload project PI during the payload proposal preparation.

EF fee schedule

The fee schedule for payload projects is defined in the NHERI WOW EF Usage Rates section. The NHERI WOW EF requires that all users pay established recharge center rates to cover costs not supported by the NSF NHERI award. The payload project PI will sign a facility Service Agreement highlighting any additional facility costs and added scope of work to the already funded main NSF project.

Intellectual property policy

The NCO and CI will develop an Intellectual Property Policy which will be requested to be signed by the EF Users (i.e. main NSF funded project PI and payload project proposer).

Contact Information

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Notes

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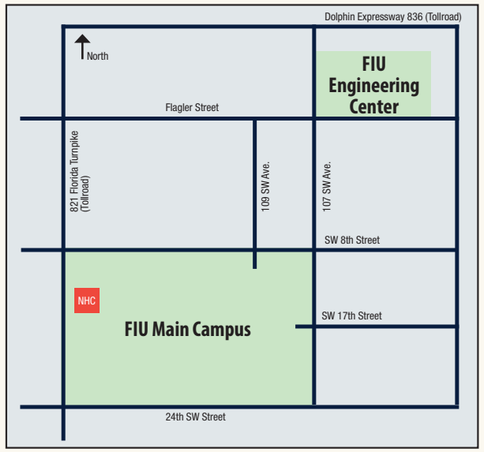
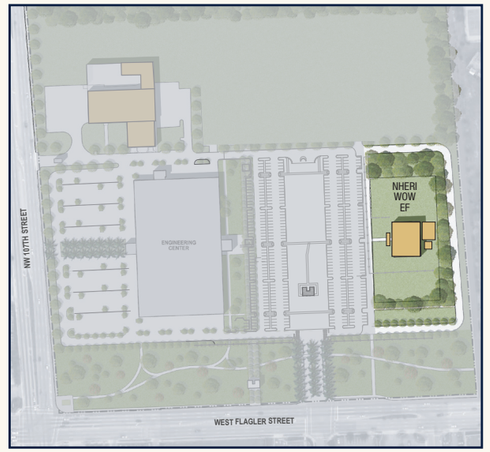


NHC= National Hurricane Center



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