NHERI Wall of Wind Experimental Facility
User Manual

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Revision History

Version	Date	Author	Comments
V1.0	October 2016	Roy Liu-Marques	Original document
V1.1	January 18, 2017	Maryam Refan	Updated info and format change

1 Introduction

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 to better understand wind effects on civil infrastructure systems and to 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 for up to Category 5 Hurricane wind speeds. The NHERI WOW EF uses a wide range of equipment, instrumentation, and experimental simulation protocols, as well as a distinguished group of faculty, staff, and a well-trained team comprised of technical and operations personnel that allow for the delivery of world-class research.

2 Your Visit to the WOW EF

2.1 Location

The EF is located at the FIU Engineering Center in Miami, Florida. The EF is conveniently located 8 miles away from Miami International Airport (MIA). Given Miami's vulnerability to hurricanes, the location of the EF for wind research is geographically relevant. The EF is within close proximity to the FIU Main Campus, which houses the National Hurricane Center co-located with the National Weather Service Forecast Office. The EF is only 3 miles away from the Miami-Dade County Regulatory and Economic Resources (RER) Department that regulates code enforcements in the Florida Building Code High Velocity Hurricane Zone and works closely with the EF team to enhance building codes, practices, and products.

2.2 Parking

Parking at FIU's campuses is governed by the rules and regulations set by FIU Parking and Transportation. Every motor vehicle parked in a non-meter space on University property must maintain a valid permit. Visitors may park on metered parking spaces located throughout the University at a cost of 25 cents per 15 minutes. Must meters allow the option on paying at the meter or use pay by phone.

Virtual permits may be purchased per day or for 30 days at the Parking and Transportation offices located at PG-5 Market Station on the Modesto A. Maidique Campus or online at parkling.fiu.edu.

2.3 Internet Access

While on campus, visitors may access the internet through a wireless connection by registering the device (computer, smartphone, tablet, etc) online at https://network.fiu.edu/visitor/. The guest ID will grant access to the FIU Wi-Fi network for 24 hours. FIU also offers EduRoam, which is a secure worldwide roaming access service developed for the international research and education community. It allows students, researchers and staff from participating institutions to obtain Internet connectivity across campus. Find more information on EduRoam at https://network.fiu.edu/#eduroam.

2.4 Office Space

Researchers, visiting students and staff will have office space available for the duration of their stay at the WOW EF.

3 Safety and Training

Health and Safety of students, faculty, staff, visitors and users is of the utmost importance at FIU and the Wall of Wind (WOW) Experimental Facility. Making safety an inherent part of the work day and culture is vital for maintaining a safe working environment. Because the WOW is at the forefront of helping the public build resilient communities through hurricane mitigation research, it emphasizes the importance of mitigating hazards in the work place and aligns us with our commitment to create a 'Worlds Ahead' facility.

We strive to maintain a safe working environment for all by implementing safety protocols and training and being proactive in addressing any safety concerns through risk management assessments and periodic inspections.

A summary of our safety plan and policies is presented in here. For the comprehensive safety plan for the Wall of Wind EF refer to the "Safety Plan" document.

3.1 Wall of Wind Host

Our visitors, users and clients are important to us and we want you to be aware of safety precautions at the Wall of Wind (WOW) Experimental Facility. If you need any assistance while you are with us, please notify the Laboratory and Environmental Health and Safety Manager, Walter Conklin.

3.2 Personal Protective Equipment

While visiting the WOW the following personal protective equipment is required:

- Hard Hat (Provided by WOW)
- Appropriate footwear (open-toed footwear of any type is not permitted)
- Safety glasses with permanent side shields or safety goggles if you are not on a tour (Provided by WOW)

3.3 Safety Awareness

You are visiting a working research and testing facility. Please remain in designated safe areas at all times. Should you wish to more closely observe a particular operation or process, please advise the Laboratory and Environmental Health and Safety Manager and we will do our best to accommodate your request safely.

Be aware of the following hazards:

- Tripping hazards from the temporary use of power cords, step offs, large door rails, etc.
- Forklift
- Screws, nails and other materials that may have become loose due to testing or construction of a test specimen

Please remain clear of any moving equipment and always be aware of your surroundings.

Users and Clients may require additional safety training when working in the Experimental Facility.

3.4 In An Emergency

- Should you become aware of any emergency, please notify your host immediately. Your host will determine if other FIU personnel need to be contacted regarding the emergency and if local municipal authorities should be contacted via the 911-response system.
- All exits are clearly marked and emergency lighting has been provided in the event of a power outage.

3.5 Smoking

Effective January 1, 2011 Smoking and/or use of tobacco product has been prohibited in all areas of the university campus. We thank you for helping make our University a healthier place!

3.6 Photography

Should you wish to take photos, please advise your host, who will work with you to ensure your safety while you are photographing areas that interest you. There will be no admittance and therefore no photographs or video during private client testing or preparation.

3.7 Fire Extinguishers

Fire extinguishers are located at each man-door of the facilities buildings and are marked with a “Fire Extinguisher” sign.

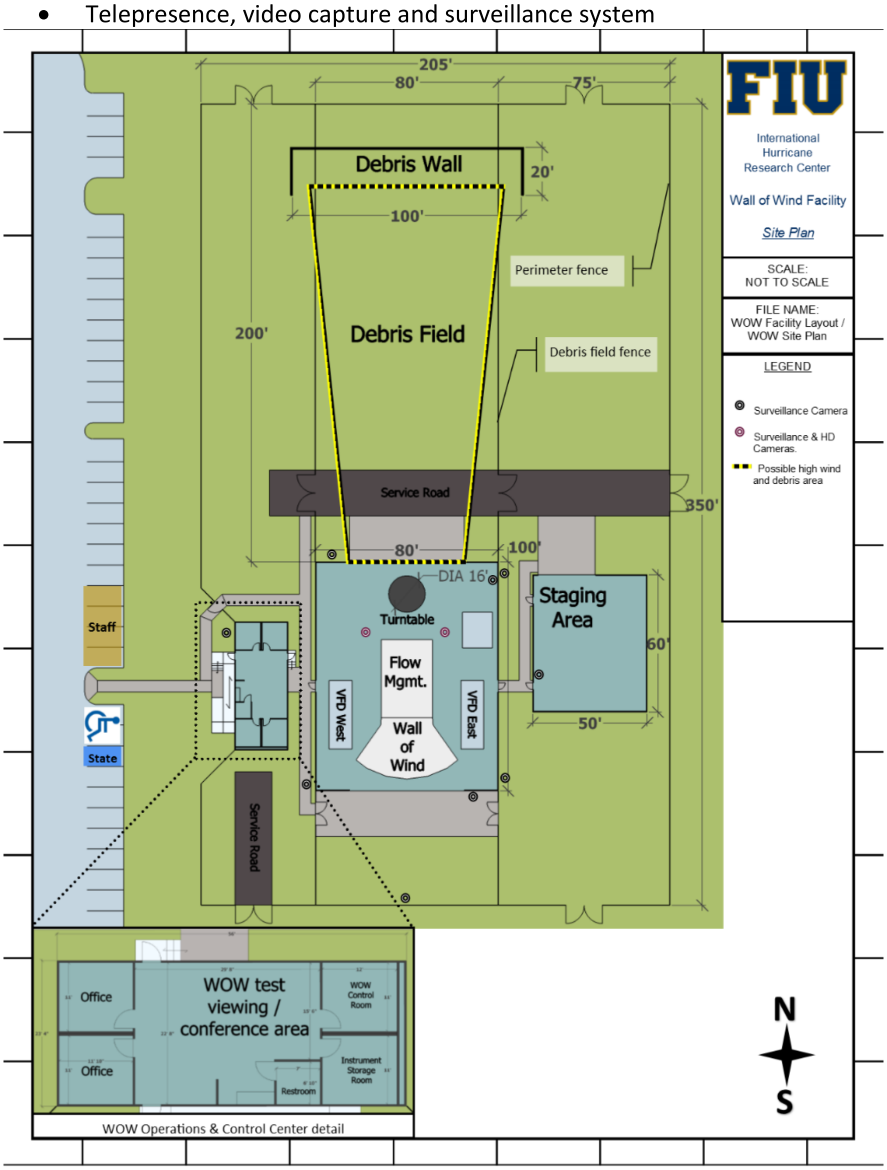
3.8 First Aid Kits

First Aid Kits are located in the WOW Operations and Control Center at the back door with the Personal Protective Equipment and at the West side door of the WOW building and at the Southwest door of the Staging building.

4 EF Resources

The NHERI WOW EF resources include:

- 16,000 square feet fenced-off secure area for wind testing
- 3,000 square feet pre-test specimen staging/construction/instrumentation building with a fabrication shop
- 12-fan WOW apparatus
- Operations and Control Center (OCC) for controlling, monitoring and viewing the tests. The OCC houses a control room, sensors storage room, and staff offices.
- 1:15 small-scale WOW apparatus
- Data uploading on to NHERI repository (compliant with CI policies)
- Diverse portfolio of measurement instruments
- Telepresence, video capture and surveillance system

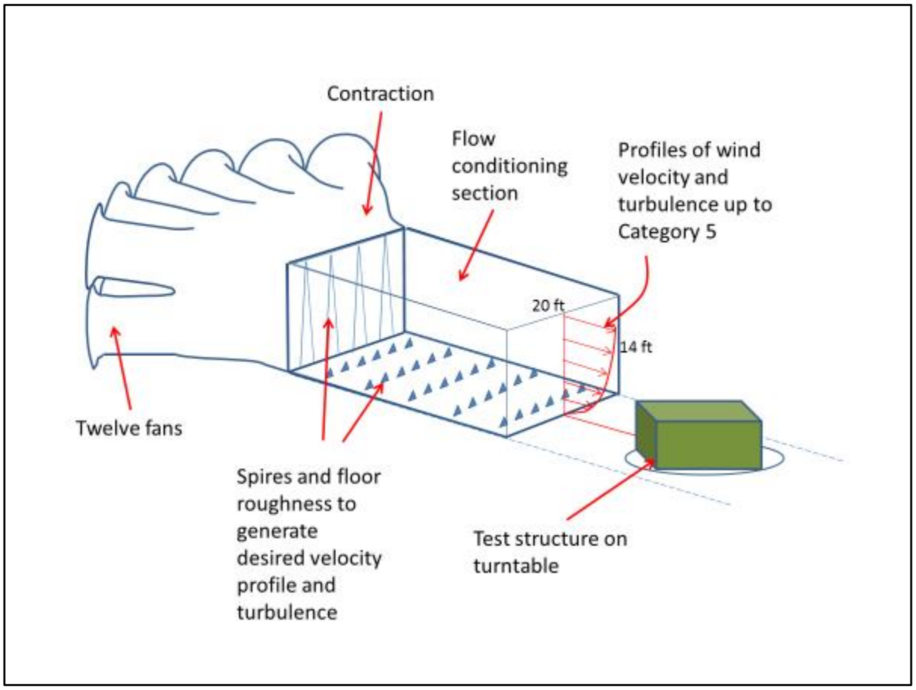


NHERI WOW EF Site Plan

Some of these resources are further introduced in the following sections.

4.1 The 12-Fan Wall of Wind

The 12-fan Wall of Wind (WOW) is an open-circuit wind tunnel that allows for large scale and high speed testing of various structures and buildings under extreme wind conditions.



Schematic drawing of the 12-fan WOW apparatus

This tunnel comprises of twelve electric fans located at the intake section in an arc-focal arrangement. Each fan is capable of producing a maximum flow of 240,000 CFM at 700 HP. The total combined flow is 2,880,000 CFM at 8400 horsepower. The fans push air into a contraction chamber that increases the wind speed. The flow then travels through a set of triangular spires and floor roughness elements that generate the target turbulence and boundary layer profile. Using a water spray system, wind-driven rain conditions can be also simulated.

The 12-fan WOW wind tunnel characteristics are summarized below:

- 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)
- Flow conditioning spires and roughness for ABL simulations: Open, Suburban, and Uniform exposures
- Rain generation system
- 16ft (4.9m) diameter turn table
- Turn table capacity of 105,000lb (47.6 tons) static / 52,000lb (23.6 tons) dynamic and rotational speed range of 0.015-0.0014 min/deg

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

4.2 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 and SPECIFICATIONS	Quantity
Cobra probes	Wind speed and turbulence	6
Uni-axial load cells	Force (2000 lbs)	25
JR3 tri-axial load cells	6-DOF forces and moments (300 lbs force, 1500 in-lbs moment)	4
JR3 tri-axial load cells	6-DOF forces and moments (1500 lbs force, 6000 in-lbs moment)	8
JR3 tri-axial load cells	6-DOF forces and moments (2500 lbs force, 20 000 ft-lbs moment)	2
JR3 tri-axial load cells	6-DOF forces and moments (1250 lbs force, 10 000 ft-lbs moment)	1
Strain gauges	Strain	64 channels
Pressure scanners	Differential pressure	512 channels (either 384 low-pressure or 128 high-pressure)
Accelerometers	Tri-axial acceleration	18
String potentiometers	Displacement	20
LVDT	Displacement (75 mm range)	8
Laser displacement sensors	Displacement (1270 range, 1422 mm standoff, 0.0635 mm resolution)	4
Laser displacement sensors	Displacement (900 mm range, 550 mm standoff, 0.5 mm resolution)	12
Inclinometers	Rotation	3
Tri-axial inertial sensors	Tri-axial accelerometer, magnetometer and gyroscope, temperature sensor and pressure altimeter	2
Parsivel² laser disdrometers	Size and speed of precipitation	1

Rain measurement gauges	Wind-driven rain rate and rainwater deposition	2
Weather sensors	Temperature and humidity	20
Smoke generator	Flow visualization	1
HD and surveillance cameras	Test monitoring and telepresence	4

4.3 Internet and Internet2 Connectivity

As a member of both Internet2 and National Lambda Rail (NLR) research networks, FIU maintains a robust leading edge technology infrastructure which will support the EF users. FIU connects to the Internet, Internet2, and the Florida Lambda Rail through two leased fiber lines. The OCC is equipped with fully routed core with switching elements and Ethernet services for wireless network, supported by distribution layer switches providing redundancy and resiliency at the building layer. All EF buildings have network supporting Voice over Internet Protocol (VoIP) phones, end stations, routers, wireless access, backup power supply, and access to FIU e-library.

4.4 Telepresence

The EF has equipment to allow its users to access the facility remotely while the test is setup or the experiments performed. A system of internet protocol (IP) and high definition (HD) cameras can stream their feed through the web to allow remote users to witness and provide input about the on-going activities without having to be physically present at the EF.

The users will be able to see the video feed live and some of the data being collected could be also streamed live without affecting the data collection process.

Due to safety regulations, only video streaming will be provided and not remote control of any of the EF's equipment and/or instrumentation. These will be operated by EF staff and personnel up to the highest standards to ensure that all safety and quality guidelines take place from the beginning up to completion of the project.

The user will be able to provide feedback real-time, to modify the test sequence, halt the experiments or make changes to the test plan.

5 Services We Provide

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

- Support for NSF proposal development
- Design, construction, and 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)

- Safety and user training
- Telepresence for remote participation
- Outreach and dissemination
- Office space and internet service for users during their visit

To enable effective use of the EF resources, users will be provided with a suite of services, i.e., planning, training (including safety guidelines), test preparation, execution/quality assurance, and data management.

5.1 Planning

- PIs and EF Site Operations Manager will inform potential users who are preparing NSF proposals on EF resources, capabilities, services, and recharge center rates.
- NSF funded users will be assisted with planning of test procedures, specimen design, and scheduling (coordinated with NCO).

5.2 Training

Training will be provided in two modes:

- Online year-round training, through NHERI web-based training modules with tutorials (coordinated with CI), to assist potential EF users submitting NSF proposals
- On-site safety training of NSF-funded users by EF Lab/EH&S Manager on site access, operations and safety policies, personal protection equipment (PPE), and emergency contacts

5.3 Test Preparation

- EF Lab/EH&S Manager will provide users with access to the staging/construction/instrumentation (SCI) building to oversee specimen construction and instrumentation, aided by the EF Testing Technologist
- EF technical staff will install instrumented specimens on the turntable, perform necessary connections for sensor data acquisition and video imaging, and change test configurations and prepare test set up as needed (e.g., set up flow management spires and roughness elements for switching between ABL profile simulations, change nozzles for various rain parameters)

5.4 Execution, Data Quality Assurance and Data Management

- EF Wind Engineering Specialist will assist the users with test protocol implementation, EF software application, and specialized data analysis, if needed
- The EF IT Specialist will provide users with access to telepresence and the Operations and Control Center (OCC) for remote and live participation, monitoring, and feedback
- The EF Project Engineer will perform instrument calibration, operate the WOW with appropriate quality and safety standards, and acquire sensor data and high definition videos. Data quality assurance (DQA) checks will be performed to verify the reliability of test data
- Generated 'data packages' will be archived by the IT Manager and uploaded to the NHERI data repository in compliance with CI's cybersecurity policies
- EF staff will facilitate post-test specimen removal/disposal and cleanup

- Users will be provided access to business-support services (wireless Internet, printing, telephones, office spaces, office supplies)

6 Wind Field Validation

Refer to “Wind Field Catalog” document.

7 Wind-Driven Rain Validation

Refer to “Wind-Driven Rain Catalog” document.

8 Data Management

Refer to “Data Management Plan” document.

9 Instrumentation and Calibration

9.1 Data Acquisition

Signals from different instruments can be monitored and recorded by one or a combination of data acquisition (DAQ) systems available at the WOW-EF. From these, the most versatile DAQ system is known as WOW-DAQ. It can be customized to take different types of signals (voltage and strain) simultaneously and record them into a single file. Some specialized instruments require separate DAQ systems to handle a high channel count and high sampling frequencies. For comprehensive information on data acquisition, refer to “Standard Operating Procedures for Instrumentation” document.

9.2 Calibration

All equipment and instrumentation are calibrated according to EF’s Standard Operating Procedures for Instrumentation and manufacturer’s guidelines. Three types of procedures are standard at the EF to verify the accuracy and correct operation of instrumentation: calibration validation, field calibration and factory calibration. When instrument-specific calibration equipment is available at the EF, the instrument’s existing calibration will be validated. If it is within the specified accuracy it is good to be used during the experiments, otherwise the equipment must be recalibrated by: a field calibration or a factory calibration. If the test equipment has been calibrated against known standards, a field calibration can be done on the instruments at the EF. When a higher accuracy calibration, NIST-traceable calibrations or calibrations that require equipment not available at the EF is needed, a factory calibration will be performed by the manufacturer or a certified calibration facility. For comprehensive information on calibration, refer to “Quality Assurance Program” document.

10 Test Protocols

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 and, if applicable, rain parameters, test duration, data sampling rate, and safety procedures. In addition to Manufacturer's Instruction Manuals for instruments, *Standard Operating Procedures* (SOP) are available to ensure correct installation, calibration, and operation for each type of instrument available at the EF.

10.1 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.

10.2 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.

10.3 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.

11 Cyberinfrastructure and Cybersecurity

Refer to "Master Information Security Policy Procedures" document.

12 Recharge Center Rates

Refer to "Usage Rates and Cost Breakdown-Federal" documents for the cost structure and usage rates.

13 Meet the Team

Arindam Gan Chowdhury, PhD
Laboratory Director, Associate Professor
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Arindam is an expert in wind and structural engineering and has co-authored more than 30 peer-reviewed journal publications. As a principal investigator, he has received more than $3.5 million in research funding from the National Science Foundation, NOAA, Florida Department of Emergency Management, Sea Grant Programs, Department of Energy, and the industry. Recipient of the National Science Foundation's prestigious "Faculty Early Career Development Program Award (CAREER)," Florida Sea Grant's "Research to Application Award," and FIU President's Council "Worlds Ahead Faculty Award."

Ioannis Zisis, PhD
Assistant Professor
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Ioannis has been studying wind effects on the built environment for the past 8 years. His research focus is structural and environmental wind engineering. He has been using advanced experimental methods, including wind tunnel and full-scale monitoring techniques, to examine how residential and other structures react to extreme wind events. The outcomes of his research efforts are aiming at the development and improvement of national and international wind standards and building codes of practice.

Peter A. Irwin, PhD
Professor of Practice in Wind Engineering
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Peter is a renowned wind-engineering expert who comes to FIU with over 20 years of experience as a highly sought-after wind-engineering consultant. He spent 6 years with the National Research Council of Canada before moving into private engineering consulting with RWDI, Inc. He has done wind consulting for some of the most ambitious building projects on record, including the Petronas Towers (Malaysia), Taipei 101 (Taiwan) and Burj Khalifai (Dubai).

Maryam Refan, PhD
Site Operations Manager
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Maryam received her PhD in 2014 from the University of Western Ontario in the field of Wind Engineering. She is an experimentalist with 6+ years of experience ranging from hands-on research to proposal development to full management of multiple projects in the field of wind engineering involving a broad range of facilities, industries, measurement techniques and, interacting with diverse users from academia, industry and government. Prior to joining the Wall of Wind team in 2016, Maryam worked at the WindEEE Research Institute as a Research Scientist.

Walter A. Conklin
Laboratory Manager
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Walter joined the team during the development of the 6-fan Wall of Wind. The knowledge he acquired while working on numerous research projects and project management at the Applied Research Center at FIU proved invaluable in getting the Wall of Wind off the ground. His work has given continuity to the project and has managed the construction and commissioning of the 12-fan WOW.

Roy Liu-Marques
Project Engineer
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Roy joined the team during the early stages of development of the 6-fan Wall of Wind while pursuing his Master's degree in Civil Engineering. He has acquired over 6 years of unique experience while involved with the International Hurricane Research Center and the Wall of Wind. He assists with the technical aspects to the research and development of the WOW and related projects, as well as managing commercial testing projects.

Raphael Greenbaum
Research Specialist
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Raphael is a Research Specialist at the Florida International University Wall of Wind experimental wind tunnel facility. At the Wall of Wind, his primary duties involve data quality assurance, improving data acquisition processes, and improving equipment control processes. Raphael received his PhD in Civil Engineering and Engineering Mechanics from Columbia University in 2014. His research focus was the experimental validation of rocking motion of rigid bodies models. At Columbia, he also developed, installed, and monitored a construction vibration monitoring system for various museums in the Northeastern US.

Ashkan Rasouli, PhD
Research Specialist
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Ashkan received his B.Sc. degree in Aerospace Engineering from Amirkabir University of Technology, Iran in 2003 and continued his education in the field of Aerodynamics at Sharif University of Technology, Iran and obtained his M.Sc. degree in 2006. Afterwards, he started his Ph.D. studies at the University of Western Ontario's Boundary Layer Wind Tunnel in Wind Engineering and obtained his degree in 2011. He joined WindEEE Research Institute as a postdoctoral researcher from 2011 to 2012 and worked in an industrial environment as a mechanical engineering manager prior to joining the Wall of Wind Experimental Facility.

Bodhisatta Hajra, PhD
Research Scientist
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Bodhi joined the WOW team in September 2015 as a Research Scientist following his postdoctoral work at Western University, Canada. He assists the WOW team with the preparation of reports and proposals pertaining to commercial projects at the WOW. His research incorporates structural and environmental aspects of wind engineering.