RAY W. HERRICK LABORATORIES
ANNUAL REPORT
SUPPLEMENTAL INFORMATION

2020

HOME OF THE CENTER FOR HIGH PERFORMANCE BUILDINGS

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THE RAY W. HERRICK LABORATORIES **AT A GLANCE**

The Ray W. Herrick Laboratories turned 60 years old in 2018. Today, we are part of the School of Mechanical Engineering, but the 28+ Mechanical Engineering faculty and Architectural Engineering faculty who do research here collaborate on interdisciplinary research projects with faculty in the other Schools of Engineering and also with faculty in the College of Science, College of Health and Human Sciences, and the Purdue Polytechnic Institute. There are four main technical areas of research with some overarching themes related to energy utilization and efficiency, reduction of pollutants in the environment, quality of life, and sustainability and safety.

The main technical areas are:

1. High Performance Buildings, Thermal Systems, and Air Quality
2. Noise and Vibration Control, which includes research on Acoustics, Dynamics, and Materials
3. Electromechanical Systems & Advanced Engines: Controls, Signal Processing, Sensing, Estimation, Diagnostics, and Prognostics
4. Perception-Based Engineering: Modeling of Human Response for Machine and System Optimization

The educational experience at Herrick combines the traditional training of aspiring researchers with exposure to industrial and government needs and the culture. Students study in a strong peer education environment with active mentoring from faculty and sponsors. Nearly 900 Masters and Ph.D. candidates have graduated from the Ray W. Herrick Laboratories.

The engagement/service programs are highlighted by the well-established conference and short course activity sponsored by Herrick. In addition, technology transfer to sponsors is an integral part of a majority of the research programs. The researchers are also widely published across the spectrum of publications from academic journals to the popular press.

MISSION
An institution dedicated to graduate education through engineering research with an emphasis on technology transfer.

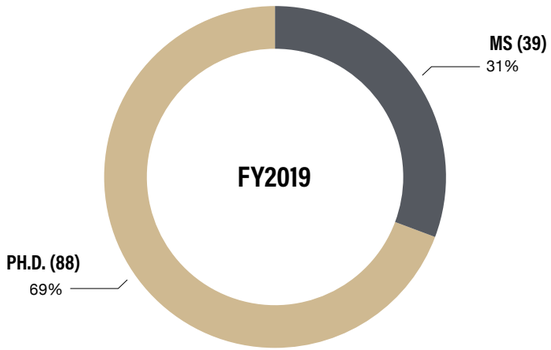
VISION
To overcoming barriers between knowledge creating, transfer, and utilization for the advancement of society.

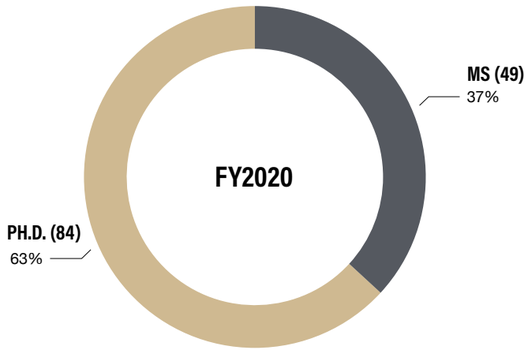
GOALS FROM OUR LAST STRATEGIC PLAN
1. Grow educational outreach activities, including fundamental, applied, and experimental short courses;
2. Build on research excellence of following research area: Noise and vibration control, integrated thermal and power systems, and the built environment;
3. Provide the education environment of the labs so that its graduate students are multi-disciplinary engineers who rate as the top engineering graduates' in the country;
4. Recognize and promote the value of Herrick through effective brand management (internally and externally);
5. Maximize utilization of new facilities;
6. Continue recruiting top faculty, grad students, and staff to ensure long term stability and growth. Maintain world-class facilities;
7. Become a more multi- and inter-disciplinary laboratory by inviting researchers from additional departments across Purdue to become involved in research at Herrick; and
8. Develop a testing program to support staff and infrastructure.

HERRICK PROGRAMS & DEMOGRAPHICS

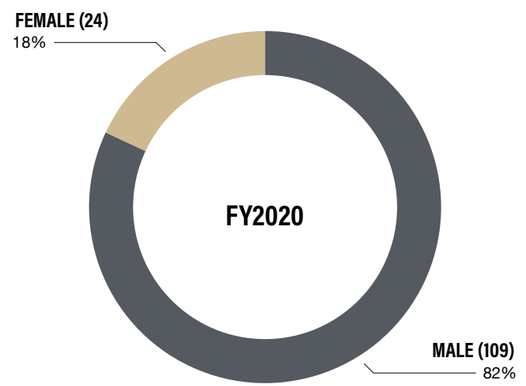
The primary educational mission at Herrick is thesis-based graduate education. We believe that the experiential learning, the open-ended, and integrative nature of thesis-based research is outstanding preparation for both academic and industrial careers. To complement the student/advisor relationship, Herrick offers a learning community to the student. This community includes an outstanding cohort of graduate students, as well as a staff prepared to support and teach. In many cases, the student's research is sponsored. Sponsor representatives also participate in educational activities with the student. We also have programs where graduate students do internships in industry or government laboratories. In total, we believe this is an outstanding educational opportunity for our graduate students.

MASTERS & PH.D. STUDENTS

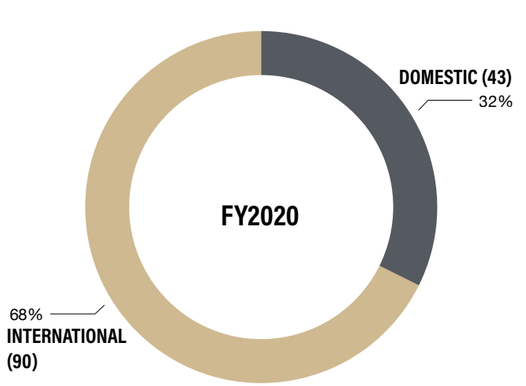




MALE & FEMALE



DOMESTIC & INTERNATIONAL



HERRICK SPONSORS

TOP 5 FEDERAL SPONSORS

2019

2020

TOP 5 INDUSTRIAL SPONSORS

2019

2020

NEW HERRICK FACULTY SPOTLIGHT

REBECCA CIEZ

ASSISTANT PROFESSOR OF MECHANICAL ENGINEERING AND ENVIRONMENTAL AND ECOLOGICAL ENGINEERING
PH.D. 2018 CARNEGIE MELLON UNIVERSITY

BIO: Dr. Ciez focuses her research on the intersection of performance, technology adoption, and public policy for energy technologies. Central to her work is the role that electrochemical energy storage plays in decarbonizing the electricity and transportation sectors. Most recently, Dr. Ciez was a Postdoctoral Research Associate at Columbia University.

She earned her Ph.D. in Engineering and Public Policy from Carnegie Mellon in 2018, and her B.S. in Mechanical Engineering from Columbia University in 2013. She also spent time as a Postdoctoral Research Associate at Princeton's Andlinger Center for Energy and the Environment.

SELECTED HONORS AND AWARDS

- Andlinger Distinguished Postdoctoral Fellowship (2018-2020)
- Carnegie Mellon GSA/Provost Office Graduate Project Research Grant (2017)
- NSF Graduate Research Fellowship (2015-2018)
- Neil and Jo Bushnell Fellowship (2014)
- Friedman Fellowship (2014)
- Columbia University King's Crown Civic Responsibility Award (2013)

RESEARCH INTERESTS: Electrochemical energy storage; microgrids; decarbonized transportation systems; energy policy and economics

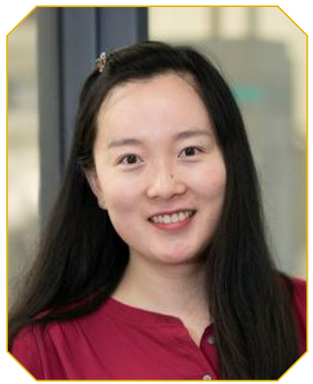
PROFESSIONAL ACTIVITIES: Member: ASME, USAEE; Organizing Committee Member, AICHE Center for Energy Initiatives Battery and Energy Storage Workshop (2019)

RELATED LINK: Rebecca Ciez Research Page

LINK TO CV: Rebecca Ciez

TIAN LI

ASSISTANT PROFESSOR OF MECHANICAL ENGINEERING
PH.D. 2016, UNIVERSITY OF MARYLAND, COLLEGE PARK



BIO: Dr. Tian Li is an Assistant Professor of Mechanical Engineering at Purdue University. She received her Ph.D. from the University of Maryland. She conducts research on energy conversion, thermal science, energy efficiency and smart materials toward energy and sustainability. She leads the Materials & Mechanics & Manufacturing (MMM) Lab at Purdue University that focuses on the nanostructured materials and multiscale mechanics with scalable manufacturing. She has received several awards, such as the Forbes 30 under 30 in Energy, and was an R&D 100 Finalist in 2020.

SELECTED HONORS AND AWARDS

- R&D 100 Finalist (2020)
- MRS Postdoctoral Award (2020)
- Forbes 30 Under 30 (US) in the energy category (2018)
- Finalist in "Energy Ideas to Change the World" Pitch Competition in ARPA-E (2016)
- ECE (Electrical and Computer Engineering) Distinguished Dissertation Fellowship (2015)
- Outstanding Graduate Assistant Award in University of Maryland (2015)
- Dean's Doctoral Research Award Finalist (2015)
- Distinguished Summer Research Scholarship (2013)

RESEARCH INTERESTS: Energy efficient building envelope; energy conversion and thermal science; smart material towards energy and sustainability.

PROFESSIONAL ACTIVITIES: Member: MRS, ACS, ASME; Contributing Editor-Special Issue in Advanced Fiber Materials; Paper reviewer for: Science, Nano Letters, Matter, Energy Storage Materials, Applied Physics A

RELATED LINK: Tian Li Research Page

LINK TO CV: Tian Li

DAVIDE ZIVIANI

ASSISTANT PROFESSOR OF MECHANICAL ENGINEERING
ASSOCIATE DIRECTOR OF CENTER FOR HIGH PERFORMANCE BUILDINGS
Ph.D. 2017, GHENT UNIVERSITY, GHENT, BELGIUM

BIO: Dr. Davide Ziviani is an Assistant Professor of Mechanical Engineering at Purdue University as well as the Associate Director of the Center for High Performance Buildings. He received his Ph.D. from Ghent University in 2017. He is an enthusiastic and dedicated personality with a solid background in energy systems, fluid dynamics and thermodynamics.

SELECTED HONORS AND AWARDS

- Best Student Paper (Cooling and Heating track) and Overall Best Paper, Rankine Conference (2020)
- ASHRAE Undergraduate Equipment Research Grant (2020)
- Best Student Paper Award, International Conference on Compressors and their Systems, City University of London (2019)
- Best Student Paper Award, International Compressor Engineering Conference, Purdue University (2018)
- ASME KCORC Scholarship (2013)
- ASME IMECE "AES Best Paper Award" (2012)

RESEARCH INTERESTS: HVAC&R technologies; advanced heat pumping systems; non-vapor compression cycles; not-in-kind cooling and heating technologies; waste heat recovery; positive displacement compressors and expanders; working fluids; CFD applied to positive displacement machines; smart buildings and communities; deep learning techniques applied to HVAC&R systems.

PROFESSIONAL ACTIVITIES: Member: ASHRAE; Research Chair: ASHRAE TC 8.1 "Positive Displacement Compressors"; Vice-Chair: ASHRAE TC 8.3 "Absorption and Heat Operated Machines"; Member: ASHRAE TC 8.11 "Unitary and Room Air-Conditioners and Heat Pumps"; Member: ASHRAE TC 1.3 "Heat Transfer and Fluid Flow"; Editorial Committee Member and Board Member (January, 2020): Knowledge Center for Organic Rankine Cycles (KCORC) Foundation; International Institute of Refrigeration (IIR): Member of Commission B2 "Refrigerating Equipment"

RELATED LINKS: Center for High Performance Buildings
Davide Ziviani Research Page
Resilient Extra-Terrestrial Habitats (RETHi)

LINK TO CV: Davide Ziviani

RECENT HERRICK LAB GRADUATES

NAME	DEGREE	PROFESSOR(S)	THESIS SUBJECT
Agrawal, Ankit	Ph.D.	Gonzalez	Particle Mechanics and Continuum Approaches to Modeling Permanent Deformations in Confined Particulate Systems
Akash, Kumar	Ph.D.	Jain	Reimagining Human-Machine Interactions Through Trust-Based Feedback
Allen, Cody	Ph.D.	Shaver	Advancing Diesel Engines Via Cylinder Deactivation
An, Ze	MSME	Cappelleri	Agricultural Robotic Platform for In-Row and Under Canopy Crop Monitoring and Assessment
Browne, Florian	Ph.D.	Jain	Robust Iterative Learning Control for Linear Parameter-Varying Systems with Time Delays
Caskey, Stephen	Ph.D.	Groll	Analysis of Thermally Connected Residential Appliances
Choi, Jongseong	Ph.D.	Dyke	Automatic Big Visual Data Collection and Analytics Toward Lifecycle Management Engineering Systems
Fleck, Trevor	Ph.D.	Rhoads	Investigation of Multifunctional, Additvely Manufactured Structures Using Fused Filament Fabric
Foster, John	MSME	Shaver	Advanced Control Strategies for Diesel Engine Thermal Management and Class 8 Truck Platooning
Ganne, Rajakumar	MSME	Meckl	Switched-Mode Urea Dosing Control Design for Selective Catalytic Reduction in a Diesel Engine
Gohil, Karan	MSME	Jain	Reduced-order Modeling and Design Optimization of Metal-PCM Composite Heat Exchangers
Grantz, Christian	MSME	Arrieta	Passive Vibration Mitigation Via Mechanical Nonlinear Bistable Oscillators
Guerrero de la Pena, Ana	Ph. D.	Jain	Development of a Framework for Projecting Line-haul Truck Technology Adoption and Greenhouse Gas Emissions in the U.S. Using a System-of-Systems Methodology
Hao, Kairui	MSME	Braun	Comparing the Economic Performance of Ice Storage and Batteries for Buildings with On-Site PV Through Model Predictive Control
Joodaky, Amin	Ph.D.	Gibert	Mechanics and Design of Polymeric Meta-Material Structures for Shock Absorption Applications
Joshi, Mrunal	Ph.D.	Shaver	Opportunities to Improve After Treatment Thermal Management and Simplify th Air Handling Architectures of Highly Efficient Diesel Engines Incorporating Valvetrain Flexibility
Lee, Seungjae	Ph.D.	Karava Tzempelikos	Development of Self-Tuned Indoor Thermal Environments
Lepak, Wesaam	MSME	Davies	Development of Source-Path Models to Synthesize Product Sounds of an Outdoor HVAC Unit
Ma, Jiacheng	MSME	Braun	Reduced Order Modeling for Vapor Compression Systems Via Proper Orthogonal Decomposition
McArthur, Daniel	Ph.D.	Cappelleri	Design of an Autonomous Unmanned Aerial Vehicle for Physical Interaction with the Environment
McConnell, Miranda	MSME	Rhoads	Studies of the Use of Additive Manufacturing WITH Energetic Materials
Meng, Lingwei	MSME	Arrieta	Non-Thesis

RECENT HERRICK LAB GRADUATES

NAME	DEGREE	PROFESSOR(S)	THESIS SUBJECT
Miers, Collier	Ph.D	Gibert Marconnet	Thermal Metrology for Waste Heat Systems: Thermoelectrics to Phase Change Materials
Murray, Allison	Ph.D.	Rhoads	Exploring the Inkjet Printing of Functional Materials and Their Use in Energetic Materials and Sensing Applications
Nash, Austin	Ph.D.	Jain	Hierarchical Combined Plant and Control Design for Thermal Management Systems
Radkar, Vaishnavi	MSME	Shaver	Characterization and Application of a Lens System Design for Engine Diagnostics and 3D Reconstructions
Range, Allison	Ph.D.	Rhoads	The Thermomechanical Response of Particulate Composite Energetic Materials Under Mechanical Vibration
Rivas-Padilla, Jose R.	MSME	Arrieta	Non-Thesis
Rohleder, Cai	MME	Groll	Experimental Analysis of Positive Displacement Compressors for Domestic Refrigerator Freezer and Air Conditioning Application
Shi, Tongyang	Ph.D.	Bolton	Sound Field Reconstruction for an Under-Determined System and Its Application
Shin, Hyunjun	Ph.D.	Bolton	Weight Minimization of Sound Packages by Balancing Absorption and Transmission Performance
Sung, Weonchan	Ph.D.	Davies	Sound Quality Evaluation of HVAC&R Equipment
Thor, Weimin	MSME	Bolton	Application of Statistically Optimized Near-Field Acoustical Holography (SONAH) in Cylindrical Coordinates to Noise Control of a Bladeless Fan
Vos, Kalen	Ph.D.	Shaver	Utilizing Valvetrain Flexibility to Influence Gas Exchange and Reduce Reliance on Exhaust Manifold Pressure Control for Efficient Diesel Engine Operation
Walls, Marlon	MSME	Rhoads	Investigating the Ability to Preheat and Ignite Energetic Materials Using Electrically Conductive Materials
Wang, Xuchen	MSME	Bolton Liu	Non-Thesis
Xiao, Yingying	Ph. D.	Karava	Distributed Solutions to Coupled Convex Feasibility and Optimization Problems on Agent Networks
Xiong, Jie	Ph.D.	Tzempelikos	An Adaptive Personalized Daylighting Control Approach for Optimal Visual Satisfaction and Lighting Energy Use in Offices
Xu, Xueyang	MSME	Groll	Non-Thesis
Xue, Yutong	Ph.D.	Bolton	Modeling and Design Methodologies for Sound Absorbing Porous Materials When Used as Layered Vibration Dampers
Zhang, Xinye	Ph. D.	Groll	Theoretical and Experimental Analysis of Dynamic Characteristics in Linear Compressors

2019 CHPB MEMBERSHIPS & PROJECT FUNDING

During 2019, CHPB featured 16 company members and 12 projects were funded spanning equipment, sensing, and building envelope topics.

CHPB CENTER FOR HIGH PERFORMANCE BUILDINGS AT PURDUE

2020 CHPB MEMBERS

BELIMO, Carrier turn to the experts, DUKE ENERGY, EMERSON, GMCC, Goodman a member of DAIKIN group, GREE, Honeywell, LENNOX, LG, Johnson Controls, REGAL, SOUTHERN CALIFORNIA EDISON An EDISON INTERNATIONAL Company, TRANE TECHNOLOGIES, Whirlpool CORPORATION

2020 PROJECT FUNDING

CHPB has funded 10 projects with 11 different faculty members as PI/Co-PI. In addition, CHPB also seed-funded 9 additional projects until the spring meeting to enable additional research and attract new companies.

CONFIRMED 2021 MEMBERS

BELIMO, Carrier turn to the experts, DUKE ENERGY, EMERSON, GMCC, Goodman a member of DAIKIN group, GREE, LENNOX, LG, Johnson Controls, REGAL, SOUTHERN CALIFORNIA EDISON An EDISON INTERNATIONAL Company, TRANE TECHNOLOGIES

15 COMPANY MEMBERS

10 FUNDED PROJECTS

11 FACULTY PIs

THE THERMAL SYSTEMS LABORATORIES

These areas are where the HVAC and Refrigeration component level and system level technology research is conducted, as well as research on Air Quality. In the original building there are two psychrometric rooms (1 pair) and in the new building there are four psychrometric rooms (2 pairs) with a temperature range of –10° to 130° F. Each psychrometric room is 7000 cu. ft. The psychrometric rooms are designed to accommodate ASHRAE/ARI standard test procedures used in rating unitary air-conditioners and heat pumps up to a capacity of 5 tons of refrigeration (18 kW). There are two indoor air quality (IAQ) laboratories that can simulate indoor and outdoor conditions. Instrumentation includes ultrasonic anemometers, omni-directional anemometers, tracer-gas sampler and analyzer, and particle generators and analyzers. Other facilities include a psychometric wind tunnel with a dust injection system; a large HVAC equipment lab with a 90 ton centrifugal chiller, and various computer controlled compressor load stands for small compressors.

THE LIVING LABORATORY

The whole of the new building is a living laboratory where the building environment is being studied. It includes a 16 bore geothermal field and plug-and-play heat rejection for experiments in the engines and thermal sciences laboratories, and four nearly identical office spaces with each unit housing 20 graduate students. Each 34 ft. by 37 ft. office is reconfigurable in different ways and have separate support systems. This enables direct comparisons of alternative technologies for windows, lighting, comfort delivery, controls, and acoustic treatments. The normal temperature range is 65° F to 75° F but this can be extended to 55° F to 85° F. Relative humidity can be varied from 20% to 80%. Comfort delivery options include air supply from the ceiling, floor, or side wall along with radiant floor heating and radiant chilled beam cooling. Three of the units have double skin facades with different options for ventilation and energy recovery. All of the offices spaces have separate equipment for providing space conditioning that are well instrumented to allow direct energy comparisons.

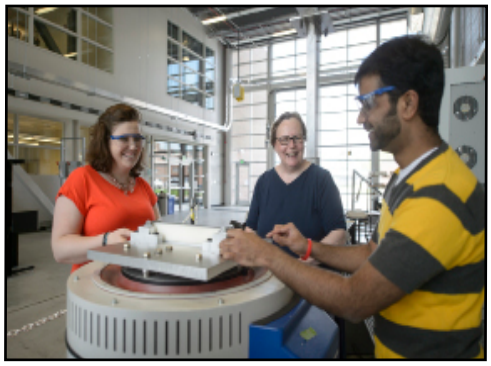
ENGINES RESEARCH LABORATORY

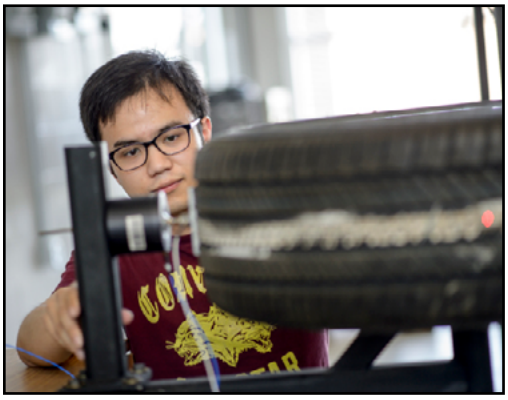
The four test cells in the new building are home to engine and hybrid systems controls research that is focused on improving efficiency, reducing engine emissions and developing efficient and environmentally friendly systems for using alternative fuels. The four test cells and associated systems will support 670, 350, 150 and 150 HP engine testing, respectively, but space and utilities are planned so that upgrading to higher horsepower and higher levels of emissions testing are possible as research progresses. Other instrumentation includes a hydraulic variable valve actuation system capable of controlling 12 valves, a single cylinder rig for testing piezoelectric valve actuation, an AC dynamometer and several eddy-current engine dynamometers, as well as emissions sensing systems.

MAJOR RESEARCH FACILITIES

HIGH-BAY FLEXIBLE LABORATORY & SMALL-SCALE VIBRATIONS LABORATORY

These spaces house electro-mechanical and vibrations research. This is comprised of two parts: an open 36 ft. by 87 ft. high-bay area with segmented floors for vibration isolation between experiments, and a smaller laboratory for smaller scale experiments. The high-bay area has high ceilings to accommodate large systems for testing. It can house large shakers, such as a 35 kN TIRA electrodynamic shaker that can be used to reproduce vibration profiles and has in-built hydraulic power supplies for hydraulic shakers. In this area, the vibration and dynamics of larger structures can be examined such as building components, vehicle suspension systems, wind turbine blades, road vehicle and aircraft and space structures. The small-scale laboratory includes apparatus for dynamic testing of materials and small structures to investigate nonlinear dynamic behavior and to identify structural and material parameters.





ACOUSTICS, NOISE AND VIBRATION RESEARCH AREA

In addition to the facilities in the High-Bay Flexible Laboratory and Perception-Based Engineering areas in the new building, these facilities, currently housed in the original building, include a 25 by 20 by 18 ft. reverberation room, an anechoic room with useful volume of 12 by 12 by 12 ft., a hemi anechoic room with useful volume of 41 by 27 by 18 ft. and an 8 by 8 ft. audiometric room for sound quality testing. There is also an acoustical materials laboratory with several types of impedance tubes for standardized acoustic material testing. The reverberation room is configured for sound transmission testing of acoustical systems. Additional facilities include a tire pavement test apparatus (TPTA) for testing tires on realistic pavements at speeds up to 50 km/hr, a two wheel chassis dynamometer with 67 inch rollers, an anechoic wind tunnel with 18 by 24 inch test section and flow velocity up 120 mph, Instrumentation includes a 64 microphone acoustical holography array and 90 channel data acquisition system, various microphones, accelerometers, shakers, laser vibrometers, and a high-speed camera.

PERCEPTION-BASED ENGINEERING LABORATORY

Perception Based Engineering (PBE) researchers study people's perceptions of stimuli, their influence on satisfaction, comfort, annoyance and performance and the relationship between those outcomes and the system, design and operational parameters. PBE faculty at Purdue work on projects related to touch interfaces, sound and vibration quality, image quality and depth perception, display design and graphics optimization, effects of noise on performance, and human-computer interaction. This 43 ft. by 28 ft. laboratory houses a TEAM 6 degree-of-freedom shaker, which can be covered when not in use. Lighting, temperature (55° F - 85° F), humidity (20% to 80%) and sound can be finely controlled, and the room can be re-configured as several small isolated rooms or one larger room, thus simulated various types of environments.