RAY W. HERRICK LABORATORIES
ANNUAL REPORT
SUPPLEMENTAL INFORMATION

HOME OF THE CENTER FOR HIGH PERFORMANCE BUILDINGS
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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.

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

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 PhD 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;
8. Develop a testing program to support staff and infrastructure.

HERRICK PROGRAMS & DEMOGRAPHICS

The MASTERS & PH.D. STUDENTS program includes:
- MASTERS (MS) and PH.D. (PHD) students across FY2019 and FY2020
- Gender distribution: MALE and FEMALE
- Nationality: DOMESTIC and INTERNATIONAL

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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
NEW HERRICK FACULTY SPOTLIGHT

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 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

NEW HERRICK FACULTY SPOTLIGHT

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

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<td>McArthur, Daniel</td>
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<td>Vos, Kalen</td>
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<td>Walls, Marlon</td>
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<td>Xue, Yulong</td>
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<td>Zhang, Xinye</td>
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The above table lists recent graduates from the Ray W. Herrick Laboratories, including their degrees, professors, and the subjects of their theses.

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The Ray W. Herrick Laboratories (RWHL) is an interdisciplinary research organization that supports and encourages both undergraduate and graduate student research across a wide range of engineering fields. The RWHL is situated at Purdue University in West Lafayette, Indiana, USA. Its mission is to foster innovation and excellence in research, education, and outreach, particularly in the areas of mechanical, aerospace, and materials engineering.
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.

CENTER FOR HIGH PERFORMANCE BUILDINGS (CHPB)

2019 CHPB MEMBERSHIPS & PROJECT FUNDING

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

2020 CHPB MEMBERS

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

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MAJOR RESEARCH FACILITIES

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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.