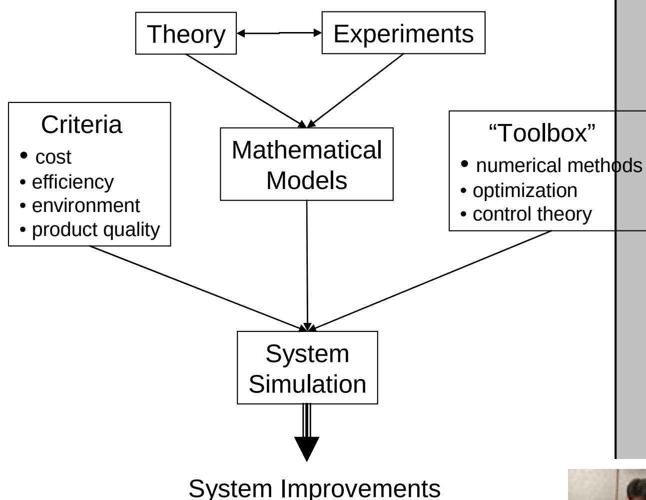
ENERGY AND ENVIRONMENTAL RESEARCH

Ray W. Herrick Laboratories
School of Mechanical Engineering
Purdue University
177 S. Russell St.
West Lafayette, IN 47907-2099
Phone: (765) 494-2132
Fax: (765) 494-0787
rhlab@ecn.purdue.edu

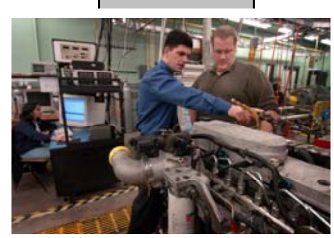
Energy and Environmental Research

Energy efficiency and environmental impact are major aspects of the research programs at the Herrick Laboratories for applications in buildings, refrigeration, and transportation. All three of these applications have major impacts on energy usage and environment. Buildings in the U.S. account for 40% of the total primary energy consumption, 71% of the electricity consumption, and 38% of the total greenhouse gas emissions. Industrial use and transportation consume 32% and 28% of the primary energy usage, respectively, and have similar greenhouse gas contributions. In addition to their impacts on greenhouse gases, combustion processes associated with these applications can have adverse impacts on local air quality. Additi transportation accounts for approximately 60% of the U.S. consumption of petroleu amount equivalent to the share from foreign sources.

The process of improving energy efficiency and reducing environmental impact involves the use of system analysis to consider performance tradeoffs, such as efficiency, environmental impact, cost, and quality. Experiments are sometimes needed to develop the fundamental understanding necessary to create and validate mathematical models. Individual process models are organized into a system simulation. Optimization techniques applied to system simulations can then be used to determine "optimal" designs or control approaches.



In order to improve sustainability of building and refrigeration systems, research at the Herrick Labs covers a range of topics including development of high efficiency components such as compressors and heat exchangers, cycles that employ natural refrigerants, energy recovery technologies, intelligent controls, and automated diagnostics. Future building systems will employ super-efficient and “smart” equipment that can automatically coordinate themselves to optimize energy efficiency and limit energy demand in response to utility rates and incentives, weather forecasts, and warnings/alerts. Research at Herrick laboratories is helping to enable this vision for the future.



Clean diesels, homogeneous charge compression ignition (HCCI) and other low temperature (LTC) combustion strategies represent significant advances for the cleaner and more efficient use of internal combustion engines (ICEs). In order to model, design and control these advanced ICEs researchers at Herrick are studying the physics of these new combustion methodologies and their dynamic coupling with other components on the drivetrain. Of additional importance at Herrick is the efficient and clean application of these approaches to alternative fuels (e.g. biodiesel, ethanol and coal-to-liquid fuels) in order to reduce our nation's dependence on foreign sources of petroleum.

Another extremely important area of research within the Herrick Laboratories is focused on new knowledge and technologies for improving indoor environmental conditions for humans, such as for interiors of buildings and airliner cabins. This includes research on contaminant and noise transmission and mitigation. The investigations use advanced computer software and experimental mockups to simulate enclosed environments in terms of airflow, contaminant transport, air temperature distributions, acoustics, etc. The studies aim at creating comfortable, healthy, and secure interior spaces with little energy consumption by the corresponding environmental control systems.

Energy and Environmental Research in Thermal Systems

From its beginning in the late 1950's to the present day, research in the areas of thermodynamics, heat transfer and fluid mechanics (thermal systems) has been an integral part of the Herrick Laboratories. Primarily this research has been in cooperation with the heating, ventilating, air-conditioning and refrigerating (HVAC&R) industries. Since 1958, over 300 students (approximately one-third at the doctoral level) have earned advanced degrees through their research in HVAC&R. Early work in the areas of heat transfer and thermophysical properties was geared towards improving the efficiency of equipment. Over time, equipment research evolved to include issues of product cost, reliability, comfort, noise and vibration. With the advent of high-speed digital computers, the focus of much of the work changed to *mathematical modeling and simulation*, including *computer-aided design* (CAD) and computerized design *optimization procedures*. The development of computer simulation tools not only improved the capabilities for equipment design and analysis, but has also provided practical methods for designing and analyzing complete systems.

During the energy shortages of the 1970s, *energy utilization* became a focus of the research programs. Illumination, heating and cooling of space, water heating and refrigeration in residential, commercial, and industrial buildings use about one-third of all the energy consumed in the U.S. Although traditional energy-related research has primary encompassed design and control of equipment and systems, energy consumption can also be reduced through improved maintenance and servicing. Research in this area includes the development of computer automated techniques for condition monitoring, fault detection, and diagnostics. Reducing electric utility power demand through the use of new systems (e.g., thermal storage) and controls is also an important research area.

In recent years concerns with the *ozone depletion* and *global warming* problems have become additional focal points of the HVAC&R research programs. Prior to their phase-out, approximately one-third of the chlorofluorocarbons (CFCs) consumed in the U.S. were used in refrigeration and air-conditioning. CFCs are considered a major factor in ozone depletion and global warming problems. The changeover from CFCs to alternative refrigerants has had a major impact on equipment design and may also affect energy use. The next major environmental issue will probably be global warming. Many of the current refrigerants have a high direct global warming potential. In addition, global warming is strongly influenced by the energy efficiency of HVAC&R products, because the burning of fossil fuels generates CO_2, a major greenhouse gas.

The use of HVAC systems does not necessarily create a healthy indoor environment. Indeed, reports of symptoms and other health complaints related to indoor environments have been increasing. However, the majority of health problems reported in buildings (namely, nonspecific complaints sometimes called the sick building syndrome) cannot be attributed to specific exposures. Available evidence suggests that multiple factors are involved, including indoor air quality; physical conditions such as temperature, humidity, lighting, and noise; and social and/or psychological stressors. Poor indoor environment conditions cost around $20 to $160 billion in lost wages and productivity, administrative expenses, and health care in the U.S. Our research has thus focused on sustainable and environmentally-friendly building designs with more energy-efficient technologies for improving indoor environment, comfort, health, and safety. The technologies developed, such as natural ventilation and displacement ventilation systems, can substantially reduce greenhouse gas emissions and save money. Reduction in energy use and pollutant emission by those technologies can benefit global sustainability and energy conservation. Therefore, those technologies are contributing to the solution of the indoor environment and global pollution problems.

Furthermore, the terrorist attacks on New York City and Washington D.C. on September 11, 2001 and the following anthrax dispersion by mail have spawned concerns about various possible forms of terrorism, including airborne/aerosolized chemical and biological warfare agent (CBWA) attacks. Current enclosed environments, such as buildings and airliner cabins, are vulnerable, since they are not designed for such an attack. How to design a safe and secure enclosed environment that can protect occupants from such an attack is an urgent issue for the designers. Our effort in recent years has been at the development of fast and accurate models that can numerically simulate those attack scenarios and provide control strategies to protect occupants from such an attack.

In order to address both industry and societal concerns within the area of HVAC&R, fundamental engineering approaches to design and control of equipment and systems are needed. HVAC&R research is aimed at removing the scientific barriers to good designs, good control, development of suitable standards, and the utilization of proper materials. The HVAC&R area is an interdisciplinary research effort which includes a wide variety of projects in disciplines such as acoustics, vibrations, controls, mechanics, design, materials, thermodynamics, heat transfer, fluid mechanics, and computer science. The common goal is fundamental and applied research that will assist the HVAC&R community in the continuing evolution of improved heating and cooling equipment and systems. Research activity in the HVAC&R area is closely allied to the concerns of industry and with the programs of the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE), the

Air-Conditioning and Refrigeration Institute (ARI), the Association of Home Appliance Manufacturers (AHAM), the International Institute of Refrigeration (IIR) and the International Institute of Ammonia Refrigeration (IIAR). Most of this research is conducted at the Ray W. Herrick Laboratories, a graduate student research facility of the School of Mechanical Engineering.

All research projects have a strong educational component, and virtually all lead to theses for either a Master of Science or Ph.D. degree. Most research funding for the programs is provided by industry, reflecting an unusually close link with companies and industry associations

Air Quality

Through the Air Transportation Center of Excellence for Airliner Cabin Environment (ACER), a number of research projects have been carried out to study air quality issues in commercial airliner cabins. It is essential to use sensors to detect contaminants in cabin air. However, most of the sensors are bulky, heavy, and expensive so that they cannot be deployed in large quantities in air cabins. How to effectively measure air contaminant with minimal amount of sensors at appropriate locations is very challenging and has been one of our research focuses. With the sensor information, how to predict correctly and quickly contaminant transport in a cabin is another challenging topic. Our effort is to identify and develop further computational fluid dynamics (CFD) models for the transport of airborne contaminants in gaseous, particulate, and liquid droplet form. The models examined include Reynolds-averaged Navier-Stokes equation models and large eddy simulation. In the meantime, our research effort is seeking engineering solutions to control contaminant transport and decontamination of contaminants, such as infectious disease viruses.

Significant research has also been conducted to improve indoor air quality in buildings while conserve energy. The research has developed ventilated windows and has studied advanced ventilation systems, such as displacement ventilation and underfloor air distribution. Our effort has also dealt with designing advanced building façade.

Energy and Emissions Engines Research

Environmental concerns have resulted in tighter limits on allowable exhaust emissions from diesel engines. Specifically, allowable emissions of particulates and NO_X have been significantly reduced starting in 2007. Thus, any malfunctions on the engine that could lead to exhaust emissions that exceed the allowable limits must be diagnosed to avoid fines. With support from Cummins, Inc., researchers in the Engine Lab are devising methods to identify engine faults that give rise to increased emissions. Since no direct exhaust measurements are available, the diagnostic algorithm must be based on available engine measurements. A variety of signal processing and statistical techniques are being used to develop these algorithms.

Diesel particulate filters are a key element of emission control solutions for heavy-duty diesel engines. In another project sponsored by Cummins, methods are being developed to monitor the status of wall-flow diesel particulate filters during normal operation. Such monitoring is necessary to efficiently control diesel particulate filter filling and regenerating cycles, to maintain system integrity, and to correctly identify possible operational problems.

Environmental Noise Research

The Acoustics and Noise Control Research Program is also involved in a University Transportation Center, entitled the **Institute for Safe, Quiet and Durable Highways** (SQDH), sponsored by the U.S. Department of Transportation. This is a multi-disciplinary center, primarily with the Purdue University School of Civil Engineering, focused on finding techniques to make tires and pavement quiet while maintaining or improving current standards of safety, durability, and cost. As a result of the Institute, world class facilities have been built at Herrick Labs for testing tires and realistic pavement sections. It is expected that the research of the Institute will result in less dependence on noise barriers along highways and an improved environment particularly for people living in heavily populated areas.

The Ray W. Herrick Laboratories faculty is also active in the Center of Excellence for the **Partnership for Air Transportation and Noise Emission Reduction** (PARTNER) program, supported by the Federal Aviation Administration (FAA). The main thrusts of these efforts are aimed at understanding and mitigating the effects of low frequency aircraft noise, examining existing and new metrics to quantify the effect of airport noise on communities, land-use around airports and website design for informing the public about airport noise. A sponsored project by NASA in conjunction with FAA PARTNER program is the study of human annoyance to sonic booms. The perceptual attributes of transient events caused by shaped boom of supersonic aircraft are being examined. Further studies are concentrated on how these perceptual attributes lead to human annoyance in reaction to these events and to understand the response of the human auditory system to shaped booms.

Faculty of the Energy and Environmental Research Group:

James E. Braun (Professor of Mechanical Engineering): Thermal systems modeling, analysis, design optimization, control optimization, and diagnostics with applications to space conditioning and refrigeration systems.

Qingyan Chen (Professor of Mechanical Engineering): Indoor and outdoor airflow modeling by computational fluid dynamics and measurements, protection of buildings from chemical/biological warfare agent attacks, building ventilation systems, indoor air quality, building energy analysis.

Eckhard A. Groll (Professor of Mechanical Engineering): Thermal sciences as applied to advanced HVAC&R systems and their working fluids: alternative refrigeration technologies, vapor compression systems using environmentally friendly refrigerants, such as HFCs and natural refrigerants, analysis and optimization of individual components of HVAC&R systems, such as compressors and heat exchangers.

Kai Ming Li (Professor of Mechanical Engineering): Environmental acoustics, sound propagation outdoors, policy on the control of environmental noise, road/tire noise, design of innovative barriers in an urban environment, prediction and reduction of train/transit noise, reduction of noise in ducts for air conditioning and tunnels for road and rail traffic, room acoustics, speech intelligibility in built environment, monitoring of natural and human produced sounds in the environment, computational acoustics, physical acoustics and wave propagation in a complex medium.

Peter H. Meckl (Professor of Mechanical Engineering): Motion and vibration control of high-performance machines, adaptive control, virtual sensing, and diagnostics. Applications to manufacturing devices, robotics, and automotive engines.

Gregory M. Shaver (Professor of Mechanical Engineering): Modeling, design and control of advanced powertrains for the purpose of developing clean, efficient and practical approaches to utilizing conventional and alternative fuels. Coordination of combustion process with aftertreatment systems and hybrid powertrains. Novel combustion methodologies: Homogeneous Charge Compression Ignition (HCCI), clean diesel.

LISTING OF ENERGY AND ENVIRONMENTAL RELATED THESES

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http://www.proquest.com/products_pq/descriptions/pqdt.shtml;
Purdue University Libraries: https://www.lib.purdue.edu/access/ill/td