

Net-Zero Energy, High-Performance Buildings

What is the problem?

Buildings account for 40 percent of U.S. energy use and a similar percentage of carbon dioxide emissions, more than the transportation or industrial sectors. Emissions associated with buildings and appliances are projected to grow faster than those from any other sector. In order to ensure adequate supplies of energy and to curtail the projected growth of CO₂ emissions, it is essential that building energy consumption be significantly reduced. One way this can be achieved is through the introduction of innovative building technologies enabled by new measurement science.

In addition to energy issues, building operation practices face pressure to improve safety, security, and occupant comfort and health. Building control companies, equipment and system manufacturers, energy providers, utilities, and design engineers are under increasing pressure to improve performance and reduce costs by developing cybernetic building systems that integrate more and more building services, including energy management, fire and security, transportation, fault detection and diagnostics, optimal control, the real time purchase of electricity, and the aggregation of building stock. Measurement science is lacking to enable these systems to communicate, interact, share information, make decisions,

and perform in a synergistic and reliable manner. Specific needs include standard data models, communication protocols, user interface standards, security procedures, testing tools, and performance metrics. Overcoming these barriers is critical if cybernetic building systems are to be successful and if the United States is to obtain a significant share of the developing worldwide market for such systems.

Why is it hard to solve?

Buildings are complex systems of interacting subsystems. Past improvements in the energy performance of individual components/systems have not resulted in the expected reductions in overall building energy consumption. The industry is very sensitive to the first cost of new technologies, and performance goals, such as energy efficiency, indoor air quality, and comfort often conflict. Because a mismatch exists between who invests (builders and manufacturers) and who benefits (public), public sector involvement is necessary to overcome the initial barrier of developing the measurement science.

Performance measurements made on individual components in carefully controlled laboratory test environments are idealized and capture neither the complexities of actual building installation nor the dynamic

interactions of multiple subsystems. An integrated portfolio of measurement science capabilities is needed that not only supports innovation in the design and manufacturing of individual components and systems, but also captures the system complexities and interactions seen in a real building. Each individual measurement capability presents technical challenges, and the overall goal of significantly improved energy performance can only be achieved by applying an integrated portfolio of such measurement science capabilities.

Why BFRL?

The Building and Fire Research Laboratory (BFRL) is in a position to leverage its strong ties to industry stakeholders, academia, and standards organizations. BFRL has the needed technical expertise and an international reputation for excellence in the technical areas relevant to cybernetic building systems as a result of more than two decades of technical work and collaboration. The energy related research within this program supports BFRL's core competency in *Measurement Science for Building Energy Technologies*, and BFRL staff members have leadership positions on the key U.S. and international committees that will make use of the research results.

BFRL plans to enable and promote the use of open cybernetic building

systems with embedded intelligence for energy efficient building operations, new integrated functionality for building systems, and improved occupant comfort and safety by developing the measurement science needed to develop, test, integrate, and demonstrate the new technology. In addition, this research will provide the measurement science that will enable the development, deployment, and use of building energy technologies that will move the nation towards net-zero energy buildings while maintaining a healthy, productive, and safe indoor environment.

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Improved Building Energy Performance

Numerous technologies are emerging to reduce energy consumption in buildings, but it is often difficult to determine the performance of buildings as they are

constructed. This performance not only relates to energy consumption, but it also applies to the level of indoor environmental quality and economics of the energy measures.

The goal of the Improved Building Energy Performance program is to improve the as-constructed performance of high-performance buildings by developing and implementing the measurement science to assess the energy consumption, CO₂ emissions, indoor air quality, and cost effectiveness of buildings. The program addresses building energy, greenhouse gas emissions, and indoor air quality measurement science in a holistic, integrated manner that considers system interactions involving weather, the building envelope, control systems, and space conditioning equipment. Research efforts are focused on the development of cost-effective building energy monitoring systems, improvements in the efficiency of space conditioning equipment through self



The Building Environment and Indoor Air Quality Test House is being used to study residential indoor air quality issues including exposure to ultrafine particles from common household activities, carbon monoxide poisoning associated with the operation of emergency generators, and whole house performance of air cleaning systems.

diagnostics and enhanced design tools, providing accurate metrics to capture the performance of thermal insulation, improved measures of CO₂ emissions from facilities, and development of tools to enhance indoor air quality (IAQ) through measurement science advancements to address volatile organic compounds (VOC) emissions and advanced ventilation schemes. Metrics to assess the sustainability of buildings and to quantify the carbon footprint of buildings are an integral part of the program.

This program will transform U.S. innovation and competitiveness in the building sector by developing the means to assess next-generation building technologies needed to achieve net-zero energy buildings. Additional impacts of this program include significant reduction in the nation's CO₂ emissions and reduced stress on the electrical power grid. Previous impacts of this program have included methods of testing and rating procedures that are used exclusively throughout the appliance and solar thermal industries, leadership in the formation of the U.S. Green Building Council, and providing the technical foundation for energy and indoor air quality standards adopted by the American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE.)

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Embedded Intelligence in Buildings

A cybernetic building system integrates intelligent building automation and control systems for energy management, fire detection, security, and vertical transport. It also integrates the building systems with outside service providers and utilities. This research program aims to address building systems measurement needs in a holistic, integrated manner that considers complex system interactions and their impact on energy consumption, comfort, safety, and maintenance.

The research plan consists of eight key interrelated areas of measurement science needed to achieve successful development and implementation of cybernetic building systems with embedded intelligence. Collectively they provide a comprehensive approach that will result in a radical market transformation in building design and operation.

Expansion, certification, and demonstration of BACnet is the cornerstone upon which all other aspects of cybernetic building systems are built because it provides the basis for communication and information exchange. BACnet is a data communication protocol for building automation and control networks developed under the auspices of ASHRAE, to standardize communication between building automation devices and systems from different manufacturers. BFRL's



The NIST Virtual Cybernetic Testbed, a whole-building emulator used for a variety of integrated building system research activities.

past work has led to adoption of BACnet by more than 30 countries and most heating, ventilating, and air conditioning (HVAC) control system manufacturers. Conformance testing tools and processes have been developed and industry run certification programs are in place. It is one of the most widely used and successful standards in ASHRAE history, but that success has been primarily limited to HVAC applications. This research will remove a number of identified barriers to expanding BACnet beyond HVAC.

Another major contributor to the program is the Virtual Cybernetic Testbed (VCBT). The VCBT consists of a variety of simulation models combined with commercial and prototype BACnet controllers that create a hybrid software/hardware environment suitable for testing various integrated control system components for cybernetic buildings in ways that cannot be accomplished by testing in actual buildings. The current research focus is on expanding the capabilities of the VCBT to include additional building systems and a wider range of building types and emergency scenarios.

Other aspects of the research program include fault detection metrics and tools for HVAC equipment, automated commissioning tools, autonomous, intelligent agents for optimizing system performance, integration of building systems with a future Smart Grid, and providing building system information to emergency responders.

Work being conducted under the Embedded Intelligence in Buildings program will result in the adoption of new and improved industry standards codes and regulations. It will advance industry practices and improve productivity, life cycle cost savings, energy efficiency, and occupant satisfaction. It will also increase U.S. market leadership through the commercial application of tested, integrated, and open cybernetic building systems and concepts.

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Advanced Building Energy Technologies

The path to achieving net-zero energy residential and commercial buildings is projected to be realized from a combination of resources. Full utilization of technologies that are available today provides the means to reduce the building energy consumption on the order of 40% to 50% at no or minimum life cycle cost. Consequently, the remaining 50% to 60% of energy savings must be realized through on-site deployment of renewable



Six photovoltaic (PV) roofing products are currently being monitored to provide the data needed to develop, improve, and validate computer simulation programs that model the response of PV systems for a wide range of environmental conditions.

energy generation and by novel energy efficient solutions. The goal of this program is to develop the measurement science needed to deploy renewable and new, energy efficient technologies that will help bridge the 50% to 60% energy savings gap that remains after employing current energy conserving technologies.

The program's topical focus is on three technology thrusts: Space Conditioning, Renewable and Distributed Energy Technologies, and Cleaning and Control Technologies for Indoor Air Quality. This last focus area is important and so included because the impact of net-zero energy technologies on the indoor environment must be assessed to ensure that indoor air quality is not compromised but preferably enhanced. The technical ideas pursued within these thrusts can be placed in the following four categories:

Cost-neutral energy savings

- Apply advances in material science — nanolubricants — to improve the energy efficiency of chillers used to cool commercial buildings.
- Apply particle image velocimetry measurements, computational fluid dynamic modeling, and evolutionary computation methods for optimization space-conditioning heat exchangers.

Since the concept of the net-zero energy building includes cost effectiveness on a life-time basis, advanced cost-neutral solutions are of particular interest.

Testing and rating methodologies

- Reduce the measurement uncertainty associated with rating of photovoltaic modules.
- Develop testing and rating procedures for micro-cogeneration systems.
- Develop test methods for high-efficiency particle filtration devices.

Indoor air quality

- Enhance NIST's multizone modeling tools for indoor environmental analysis to incorporate more complete particle transport.
- Apply multizone building analysis to relate air cleaner performance as measured in the laboratory to contaminant exposure reduction in actual occupied environments.

Exploratory research

- Identify measurement science barriers that impede market implementation of alternative, emerging cooling technologies.

Collectively, the projects within this program will bring innovation and promote competitiveness in the building sector by enabling the introduction and widespread use of next-generation building energy technologies that are needed to achieve net-zero energy, high-performance buildings.

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