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Measurement Science Roadmap for Net-Zero Energy Buildings

Workshop Summary Report

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PREFACE

This report summarizes the results of the *Measurement Science for Net-Zero Energy Buildings Workshop* held on October 29, 2009 in Gaithersburg, Maryland, and sponsored by the National Institute of Standards and Technology. This effort supports and responds to the Federal Research and Development Agenda for Net-Zero Energy, High-Performance Green Buildings, issued by the National Science and Technology Council in October 2008 (NSTC 2008). Advances in measurement science are called out by the NSTC report as being critical to achieving the future promise of net-zero energy buildings.

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EXECUTIVE SUMMARY

Buildings account for nearly a third of the world's energy use today, and this share is expected to rise along with population growth and levels of prosperity. In the United States, residential and commercial buildings consumed about 40 % of primary energy use, or about 38.7 quadrillion BTUs (40.8 exajoules) in 2008. Buildings today account for about 73 % of electricity and 55 % of natural gas consumption in the United States. In 2006, residential and commercial buildings were responsible for 58 % and 42 %, respectively, of the $392 billion U.S. building energy expenditures. (DOE 2009, DOE 2009a).

Net-zero energy buildings (NZEB) —buildings that produce as much energy as they consume over a defined period—offer the potential to substantially decrease building energy use and enable buildings to become energy self-sufficient. Achieving the vision of net-zero energy buildings will require the pursuit of multiple strategies, including development of new, cost-effective technologies and practices, integration of renewable energy into building designs, and adoption of innovative strategies for using energy and resources. A national goal has been set to achieve net-zero energy in 50 % of U.S. commercial buildings by 2050 (DOE 2010).

In 2008, the National Science and Technology Council (NSTC) issued the Federal Research and Development Agenda for Net-Zero Energy, High-Performance Green Buildings (NSTC 2008). Advances in measurement science are cited by the NSTC report as being critical to achieving the future promise of net-zero energy buildings.

In response to the NSTC report and to ensure that measurement science keeps pace with needed innovations, the National Institute of Standards and Technology (NIST) sponsored the *Measurement Science for Net-Zero Energy Buildings Workshop* on October 29, 2009 in Gaithersburg, Maryland. Experts from industry, government, national laboratories, and academia came together to provide insights on critical technologies, major challenges, and related measurement issues for five major topics (see Figure E.1).

Figure E.1 Workshop Topics

- *Onsite Energy Production*—Stand-alone and building-integrated alternative energy systems
- *Intelligent Buildings*—Integrated, intelligent measurement and control technologies to improve building environment and functionality
- *Whole Building Integrated Energy Performance*—Assessment and projection of whole building energy performance
- *Building Envelope Energy Reduction*—Design, construction, and inspection methods for building envelopes, and
- *Building Equipment Energy Reduction*—Advanced and optimized building system components and equipment such as heating, ventilating, and air conditioning (HVAC), water heating, lighting, and others

This report summarizes the workshop results and will serve to guide NIST in pursuing a portfolio of programs that are focused on providing the measurement science needed to enable net-zero energy buildings. It can also be used by both the public and private sectors to guide policy, R&D, and other decision making relevant to this important area. Highlights from the workshop are summarized in Figure E.2.

Some of the broad challenges identified include financial incentives (the building industry and consumers are motivated by different and sometimes conflicting factors); industry structure and culture that is sometimes slow to change; uncertain, inconsistent, or insufficient policies and regulations that contribute to greater risk; lack of training and education to better inform all levels of stakeholders about energy issues; and a lack of public awareness about net-zero energy concepts and the potential benefits.

	Onsite Energy Production	Intelligent Buildings	Whole Buildings	Building Envelope	Building Equipment
Critical Technologies	• Electrical and thermal energy storage systems • More efficient/less expensive renewable systems • “Plug and play” renewable energy systems • Advanced CHP including CO-tolerant fuel cells • Intelligent systems to interface renewable systems, storage, and energy providers • Effective interconnection standards and interfaces	• Robust, adaptive, self configuring control strategies • New, low cost, self checking sensors • Intelligent models and feedback systems • Technologies to enable whole building global optimization • Inexpensive integrated metering	• Whole building design and methods for effective integration of envelope/ energy generation • Performance assessment software, databases, and life cycle tools • Controls/sensors for monitoring air, gas, water, volatiles, particulates • Passive air cleaning technologies	• Daylighting • Wireless sensor integration • Zero-emission materials and rating processes • High R-value building materials and comments • Advanced design and construction methods to increase quality and efficiency • Moisture-tolerant materials and assemblies	• Inexpensive long life wireless sensors and transmitters • Fault detection/ diagnostics for all equipment • Automated building/ equipment commissioning • Better electrical ‘sleep’ functions • Design tools for efficient sizing • Improved water control and use
Measurement Priorities	• Dynamic in-situ measurements of performance • Accurate tools to predict energy generation from on-site energy sources • Representative thermal and electrical building load profiles • Methods/standard protocols for evaluating real time performance of onsite generation systems • Commissioning techniques that reduce “gap” between design and actual performance • Standard tariff database	• Standards for collecting and sharing data • Test beds for developing/evaluating NZEB technology • Effective model inputs from standardized data • Automated tools for commissioning • Data requirements and analysis to assess building performance • Best practice guidelines for intelligent system design, operation and maintenance	• Fundamental basis for green codes, standards and programs • Equipment ratings to support system modeling and generate performance maps • Accurate, affordable, low maintenance sensing and measurement • Whole building energy/ environment model • Performance degradation metrics for whole building and subsystems • Universal standards /methods of measurement for buildings	• Wireless temperature and RH transducers with high accuracy, low power and cost and long life • Accelerated aging tests for predicting long-term performance of envelope materials and systems • In situ measurement of thermal resistance of existing wall assemblies • Air-tightness measurement test and calibration metrics • Analysis of energy bills to identify candidate buildings for energy-efficiency retrofits	• Updated equipment methods of test and performance rating procedures • Procedures for rating as-installed distribution effectiveness in buildings • Continuous comparative analysis of measured vs expected performance of HVAC and refrigeration • Nanolubricants for efficient chilllers

Figure E.2 Critical Technologies and Measurement Science Priorities for Net-Zero Energy Buildings

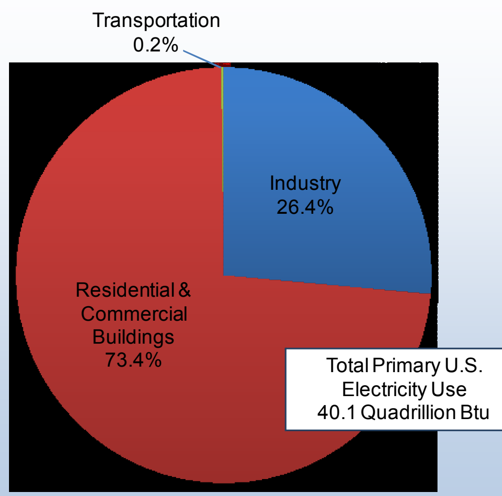
I. INTRODUCTION

A. Background and Importance of Net-Zero Energy Buildings

Buildings account for nearly a third of the world's energy use today, and this share is expected to rise along with population growth and levels of prosperity. In the United States, residential and commercial buildings consumed about 40 % of primary energy use, or about 38.7 quadrillion BTUs (40.8 exajoules) in 2008 (DOE 2009a). Buildings consume approximately 73 % of all electricity used within the United States, as shown in Figure 1. Buildings also account for 55 % of all U.S. natural gas consumption (including natural gas for electricity production) (DOE 2009a). In 2006, residential and commercial buildings were responsible for 58 % and 42 %, respectively, of the $392 billion U.S. building energy expenditures (DOE 2009). If current trends continue, buildings could consume more than industry and transportation combined (NSTC 2008).

In addition, U.S. buildings are responsible for more than 39 % of world CO_2 emissions, double the total emissions of India and more than the total emissions of the U.K., France, and Japan combined (UN MDGI-2009). Buildings are also responsible for 45 % of U.S. water use, or about 180 billion gallons (681 G·m^3) per day (USGS 2004). The per capita water use for providing electricity to buildings (470 gallons [1.78 m^3] per day) far exceeds the per capita domestic water use of about 100 gallons [0.38 m^3] Per day; a recent study projected that 36 states anticipate local, regional, or statewide water shortages by 2013.

Figure 1. U.S. Electricity Consumption By Sector, 2008 (DOE 2009a)



Without dramatically reducing energy consumption in the buildings sector, it will be difficult for the U.S. to make meaningful reductions in the fast-growing demand for electricity, water, and/or gas.

Net-zero energy buildings (NZEB) —buildings that produce as much energy as they consume over a defined period—offer the potential to substantially decrease building energy use and enable buildings to become energy self-sufficient. Achieving the vision of net-zero energy buildings will require the pursuit of multiple strategies, including development of new, cost-effective technologies and practices, revision of building codes, integration of renewable energy into building designs, and adoption of innovative strategies for using energy and resources within the building community.

A national goal has been set to achieve net-zero energy in 50 % of U.S. commercial buildings by 2050 (DOE 2010). Greater use of existing technologies plays a key role in achieving this goal. Studies have found that, by using currently available technologies, it is possible to reduce a building's energy consumption by 30 % to 50 % (Anderson et al. 2006; Griffith et al. 2007; Levine et al. 2007; USGBC 2007). Existing technologies by themselves, however, will not be adequate to achieve dramatic energy reduction goals for the buildings sector.

Buildings are complex systems with many interacting elements. Past improvements in the energy performance of integrated and interacting materials, components, and systems within buildings have not produced the expected reductions in overall energy use. An integrated portfolio of advanced technologies is needed that not only supports performance improvements in the design and manufacturing of individual components, but also captures the system complexities and interactions seen in real buildings. Additional reductions of from 20 % to 40 % can be realized by using advanced technologies integrated holistically with the building design (Griffith et al. 2007). Additional energy requirements, after current and advanced energy saving technologies are in place, must be met through the use of renewable energy systems.

The environment in which technologies are deployed must be addressed as well. Challenges include a complex industry and regulatory structure, imperfect information, high first costs, technical and market risks, and lack of a trained and experienced workforce. Technology advances, combined with new policies that address or eliminate some of these challenges, will be needed to achieve dramatic improvements in building energy efficiency.

B. Scope and Objectives

In 2008, the National Science and Technology Council (NSTC) issued the Federal Research and Development Agenda for Net-Zero Energy, High-Performance Green Buildings (NSTC 2008). This landmark report lays out goals for achieving dramatic improvements in building performance and sustainability. Advances in measurement science are cited by the NSTC report as being critical to achieving the future promise of net-zero energy buildings.

In response to the NSTC report and the need to ensure that measurement science keeps pace with the needed technology innovations, the National Institute of Standards and Technology (NIST) sponsored the *Measurement Science for Net-Zero Energy Buildings Workshop* on October 29, 2009 in Gaithersburg, Maryland. Experts from industry, government, national laboratories, and academia (Appendix B) came together to provide insights on the characteristics of the future built environment, the critical technologies and system approaches that would be needed, and the technical challenges and measurement issues related to net-zero energy buildings. Five technical topics were explored, covering both existing and new buildings:

- *Onsite Energy Production*—Stand-alone and building-integrated alternative energy systems
- *Intelligent Buildings*—Integrated, intelligent measurement and control technologies to improve building environment and functionality
- *Whole Building Integrated Energy Performance*—Assessment and projection of whole building energy performance

- *Building Envelope Energy Reduction*—Design, construction, and inspection methods for building envelopes, and
- *Building Equipment Energy Reduction*—Advanced and optimized building system components and equipment such as heating, ventilating, and air conditioning (HVAC), water heating, lighting, and others

A wide spectrum of measurement science was covered in each topical area (see Figure 2), many of which are critical to achieving net-zero energy buildings. For example, technical guidelines and methods of test form the basis for standards, codes, and best practices. Reference materials, data, measurement methods, and other tools enable the development and validation of the performance of new technologies.

Figure 2. Measurement Science Is Broadly Defined to Include:

- Reference Data
- Reference Materials
- Measurement Methods
- Methods of Test
- Test beds
- Predictive Tools
- Performance Metrics
- Comparison Studies
- Assessment of Technologies
- Information Models
- Protocols
- Technical Guidelines

Workshop Process and Results

Participants were asked to provide input on the characteristics of the future built environment; critical technologies needed to enable net-zero energy buildings; broad technical and non-technical challenges to technology development and implementation; and critical measurement barriers. To determine priorities for measurement science, participants were given five votes and asked to assign these votes to the measurement barriers they considered to be most important in terms of meeting future goals for net-zero energy buildings. Those barriers receiving the most votes then formed the foundation for detailed measurement priorities in each topical area.

The remainder of this report summarizes the results of the workshop and provides a perspective on measurement science challenges in both the near and long term. Each chapter provides the set of priority measurement topics that emerged as the most important challenges in moving toward net-zero energy buildings.

The report will serve to guide NIST in pursuing a portfolio of programs that are focused on providing the measurement science needed to enable net-zero energy buildings. It can also be used by both the public and private sectors to guide policy, R&D, and other decision making relevant to this important area.

II. Broad Challenges for Net-Zero Energy Buildings

A number of broad technology, policy, and cultural challenges were identified for net-zero energy buildings that cut across technologies and building types. The most notable broad challenges to achieve net-zero energy, high-performance green building technologies are listed in Figure 3 and discussed below.

Figure 3. Broad Challenges for Net-Zero Energy Buildings

- Financial Incentives
- Policy and Regulation
- Codes and Standards
- Industry Culture
- Energy Training and Education
- Consumer Behavior

Financial Incentives

Low cost energy is a deterrent to implementation of efficiency projects in general, as financial incentives and return on investment are less attractive when energy is inexpensive. There is also conflicting motivation between the various stakeholders associated with a building during its life.

The building industry is motivated by profit associated with the construction and sale of a building and not necessarily by reducing the operational costs of the building that will be borne by the building's occupants. Buyers are generally focused on the up-front cost and tend not to invest in future savings, as a portion of the savings may not materialize during their ownership. Realtors base home pricing on comparisons (location, square footage, etc.) which typically ignore energy savings features. A rental or leased property where owners do not bear energy costs is another example; owners have no incentive to improve building energy efficiency because renters pay for energy use. A clear value proposition is needed to facilitate acceptance of net-zero energy buildings in the investment community and establish commercial viability and potential benefits.

Policy and Regulation

A massive market transformation will be necessary to achieve net-zero energy, high-performance green buildings. Dramatic reductions in building energy consumption can be achieved only through progressive policies that support the widespread diffusion of existing technologies and the development and deployment of new advanced building technologies.

Policy disincentives (e.g., uncertain energy and carbon policy, outdated tax depreciation schedules) could discourage long-term thinking and are a major impediment. The near term focus of policy (government) actions can also be a deterrent; there is a need to focus on the longer term and changing realities to support demonstration of game-changing technology. The lack of consistent policies to support funding for R&D, as well as future policy uncertainties, also contribute to greater risk.

Codes and Standards

Codes and standards are needed to move the Nation towards net-zero energy buildings. However, codes and standards are slow to change and adapt to advances in technology and knowledge. Code adoption and enforcement is slow to occur, fragmented and inconsistent in many cases.

Industry Culture

Strong traditions in the buildings trades and professions create a culture where change is often slow. There is also skepticism regarding the use of technologies that are perceived to be risky and whether a net-zero energy buildings is a realistic goal. The industry is fragmented, with little centralized knowledge, which contributes to a lack of impetus and lack of collaboration on new technology adoption.

Training and Education

The lack of curriculum tools, interactive tools, and other information to support cradle to grave awareness of energy issues constitutes a broad challenge for net-zero energy buildings. Consumers as well as builders, installers, maintenance workers, and commercial building owners all need greater awareness of the net-zero energy building concept and its cost benefits. Technical assistance to support widespread technology diffusion and implementation in the residential and commercial building sectors must be scaled up. Workers must be trained across the spectrum of the trades to serve as the next generation of leaders via workforce development, retraining, certification, and education programs.

Consumer Behavior

More research is needed in behavioral economics to understand what motivates people to adopt energy efficient strategies. There is a general resistance to change that must be overcome. The desire to have a healthy, comfortable environment is not necessarily translated by the public into the concept of a building that uses less or no energy. Misinformation about new technology and ideas can also create public doubt and exacerbate the problem of inertia and resistance to change.

III. Onsite Energy Production

Alternative energy systems can be used to produce electricity and thermal energy at the building's site, eliminating transmission and distribution losses. Enhancements to building efficiency and the use of advanced technologies are expected to yield a 70% improvement in today's building energy profile; renewable energy systems are expected to provide the remaining 30 % to achieve net-zero energy. The nature of the technology used will depend on the electrical and thermal demands associated with the building, building design, access to alternative energy sources, and other site-specific factors.

This topic area focuses on the technologies and measurement science needs related to the use of alternative—including renewable—energy systems in commercial and residential buildings. The scope encompasses solar (e.g., photovoltaics, including building integrated and both active and passive solar thermal technologies as well as combined photovoltaic and thermal systems); wind (e.g., wall- or roof-integrated, stand-alone); onsite hydropower; combined heat and power systems; and, building integration and grid interconnectivity of these systems.

A. Characteristics of the Future Built Environment

The potential future attributes of onsite power generation technologies are summarized in Table III-1. In the future, buildings are likely to become integrated generation units, utilizing renewable energy technologies and combined heat and power (CHP) systems to become active participants in utilities' energy management activities. Ultimately, buildings would ideally become entirely self-sufficient entities, with dedicated central power generation facilities providing a minimal amount of additional electricity.

Table III-1. Onsite Energy Production – Future Built Environment
Energy Production
• Energy systems are transparent in aesthetics and operation • Characteristics: - Net positive power output from buildings to be dispatched - Aggressive conversion efficiencies - Dispatch-able loads - Low or no carbon emissions - Integrated systems to include power requirements for electric hybrid or electric vehicles • All natural resources available on the site to fully operate the building are utilized (not just solar, but also wind, geothermal, etc.) • Lower cost photovoltaics (PV); applications beyond roof tops • PV systems are fully integrated into building materials • Cost-effective solar desiccant cooling

Table III-1. Onsite Energy Production – Future Built Environment
Controls and System Integration
• Software advances that enable accurate predictions of the energy production potential associated with various alternative energy sources • Means for control and monitoring so consumers can regulate their own usage and induce long-term changes in behavior • Provide immediate feedback to stakeholders that gives the actual power generation of renewable energy systems compared to predicted/perceived performance • Advanced on-site power generation control systems • PV, solar thermal, and energy storage systems fully integrated to optimize overall performance
Energy Storage, Operations and Maintenance
• Code enforcement to ensure proper installation and operation • Lower cost PV, solar thermal, wind, and energy storage technologies

B. Critical Technologies

Advancements in both energy generation and building technology are essential for wide-scale deployment of the integrated systems that will enable buildings to generate their own energy and become largely independent of electricity supplied by the grid. Control systems, communication protocols, and materials development and testing are all vital to the emergence of net-zero energy buildings.

The following is a summary of some technology developments that will be needed to facilitate the emergence of onsite energy production for buildings. Near term, mid term, and long term are defined as 0-3 years, 3-5 years, or 5-10 years, respectively, throughout this report.

Energy Generation and Storage

Near Term: Priorities include technologies that will enable greater utilization of low-quality heat sources. Materials that enable more efficient solar PV energy capture will need to be developed and deployed.

Mid Term: Improved storage technologies will facilitate the integration of renewable energy with the grid while maintaining overall stability.

Long Term: In the field of CHP, CO-tolerant fuel cell systems, onsite natural gas reformers, and neighborhood-scale geothermal and solar heat pumps will be deployed. Technologies are needed to ensure interactivity of electrical energy storage devices with the electric grid, and integration of thermal energy storage devices with the building’s heating and cooling equipment.

Control Systems

Near Term: Intelligent controls will manage multiple remote onsite energy-producing units in order to avoid start-up demand spikes. Advanced building management systems will include fault detection and price response in order to maximize benefits from generation capabilities; these smart controllers for integrated power generation systems will include high-density energy storage for grid regulation.

Mid to long Term: There will be continued development of smart controllers for integrated power generation systems.

Integration of Systems

Near Term: A single interconnection standard will be needed to incentivize development and reduce regulatory barriers to self-generation. Uniform utility control standards that facilitate installation and communication of networked devices. Standard interfaces will enable the integration of "plug and play" PV systems. Predictive cost benefit models will assess the performance of PV systems for individual customers.

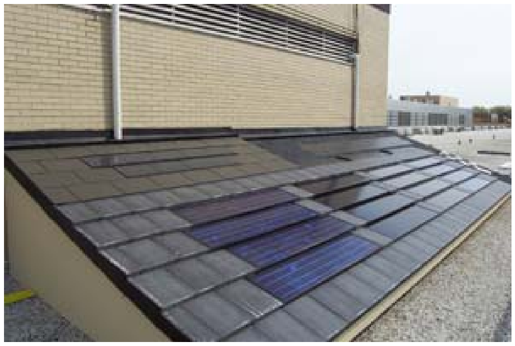
Mid to long Term: Generating technologies will be more responsive, particularly waste heat utilization and CHP; generation will be tightly managed and will be dispatch-able.

C. Broad Challenges

The broad challenges related to onsite energy production are both technical and non-technical. They involve barriers unique to the integration of generation systems with buildings, the need for energy storage, incentivizing investment for high risk, high cost renewable energy systems, and overcoming current building industry philosophies and structure.

Technical Challenges

Renewable energy systems face a number of challenges for use in buildings. Some of the most critical include reliability of renewable energy systems over time, and predicting the actual performance of these systems versus expectations based upon limited rating data—a practice that often leads to over-prediction of installed performance. Solar photovoltaic (PV) systems are impeded by the high investment required, which means long and unattractive payback periods for many building operators and owners. On the technology side, maintenance and reliability of concentrating solar collectors remains a challenge. Standard techniques to integrate PV on residential, commercial, and skyscrapers are also lacking. Communication barriers also exist between sensors, smart grid systems, and renewable energy systems. Related to this is the need for accurate predictive software and performance metrics for integrated power generation systems.



NIST's outdoor residential photovoltaic test facility is used to collect performance data for model improvement and validation. (Photo: NIST)

Urban power challenges include natural hazard control (e.g., maintaining system reliability and energy production under conditions such as hurricanes, fire, snow, hail, thunderstorms) is a challenge that needs to be resolved for urban building-integrated power generation to become more widespread. Urban power generation inherently creates some difficulties, such as noise and aesthetic concerns.

Grid-integration protocols are a major challenge to grid integration of onsite power systems. As grid interconnection becomes more widespread, there will be an increased need for communication protocols that enable utilities to provide price signals to producers and consumers of energy, as well as automatic scheduling of demand-response events.

Uniform technical methods of test, rating methodologies, and standards are needed to determine the real-time performance of energy generation. It is important to be able to reconcile predicted output with actual energy production, allowing more accurate selection and design of systems. In addition, standards are needed that will allow data collection to establish benchmarks to identify underperforming units or facilities.

Storage technology is an important issue, particularly for renewable energy technologies with variable production. The major challenge is the lack of high-efficiency, low-cost, environmentally sound storage technologies for both electrical and thermal energy. A related barrier is the lack of high-density, high-performance energy storage materials, which could enable new storage technologies.

Non-Technical Challenges

Costs and financing represents a challenge on a number of fronts. The current cost of energy conversion technologies in general is high, making them impractical for some buildings. There is also a great deal of uncertainty in appraising the performance and determining the value of onsite energy production. Increased demonstration of technologies and better sharing of results and lessons learned could help to increase understanding of benefits and reliability, particularly for investors. On the policy side, there are widely varying financial incentives for energy production, and navigating these can be difficult for the average operator, owner, or investor. A key challenge is to convey the benefits to residential users so they can readily justify adoption of systems based on cost.

Training and education is a challenge in a number of areas. First responders, for example, have limited understanding of and training with PV/energy production systems, which could raise safety concerns during hazardous or emergency conditions. On the technical side, trained installers are lacking, especially ones who understand permitting and other issues. There is also a broad lack of expertise with building-integrated energy systems in the design community.

Non-uniform regulatory requirements are an important barrier. While many states mandate that renewable and distributed energy sources must be connected to the grid and provide for net metering, these regulations are not uniform and can vary significantly between jurisdictions. There is a need to develop one nationally consistent regulatory framework that governs the integration of onsite energy production with the grid while ensuring grid stability.

Structural issues within the building industry also serve as impediments to onsite energy production. A key barrier is that the existing housing stock was not built with the application of future onsite power generation in mind, which means that significant cost could be incurred in retrofitting the building to accommodate these systems. From a cultural standpoint, the residential building industry in general is not receptive to an energy service company business model. Overcoming compartmentalized thinking in the building industry is a key challenge.

D. Measurement Barriers

A number of measurement barriers and challenges were identified that are critical to the development and implementation of onsite building energy generation. These are summarized in Table III-2 by topical area, with the relative priorities indicated.

Some of the top measurement challenges include:

- Clarification of the goals associated with renewable energy resources,
- Performance and technology assessment,
- Lack of predictive tools to optimize strategies and to evaluate energy production performance,
- Lack of real-world testing protocols to capture actual energy production performance,
- Closing the gap between design and actual performance, and
- Dynamic performance measurements of energy generation systems.

Table III-2. Onsite Energy Generation – Measurement Barriers and Challenges
(● = one vote)

Performance Metrics	
High Priority	• Uncertainty about goals and what to measure to determine performance—e.g., fuel use, carbon, source energy ●●●●●●●●
Medium Priority	• Lack of a standardized or validated tariff model and database ●●
Lower Priority	• Difficulty capturing total financial savings, including externalities (CO_2) that truly reflect PV costs • Inability to effectively determine the impact of excess PV generation on source-to-site multiplier • Developing standard rating methods that are realistic
Technology Assessment	
High Priority	• Closing the gap between design and actual performance due to lack of commissioning ●●●● • Lack of dynamic performance measurements ●●●●
Medium Priority	• Lack of understanding of optimal controls schemes for integrated power systems ●●
Lower Priority	• Lack of customer training on how to assess technology and interpret results • Limited ability to evaluate long-term performance of integrated systems

Table III-2. Onsite Energy Generation – Measurement Barriers and Challenges (● = one vote)	
Predictive Tools	
High Priority	• Lack of predictive/design tools to optimize technology strategies (i.e., integration) and demonstrate compliance ●●●●● • Lack of predictive tools/models to evaluate energy production technologies ●●●●●
Medium Priority	• Limited ability to forecast energy collection and compare with actual collection ●● • Lack of surface/shading measurements to identify obstructions to PV system ●
Lower Priority	• Lack of a standard approach to predict annual power output for onsite generation
Reference Data	
High Priority	• Limited availability of representative electrical and thermal energy use profiles ●●●●●
Lower Priority	• Lack of end-use information relative to building energy use ● • Insufficient standard irradiation data ● • Lack of agreed-upon values for CO_2 offsets in each region
Measurement and Test Methods	
High Priority	• Insufficient real-world testing methods to evaluate annual energy production ●●●●
Medium Priority	• Lack of consistent protocols for measuring and reporting performance results ●● • Lack of accelerated aging testing methods to assess onsite power generation equipment ●● • Limited test procedures to capture benefits of hybrid solar/thermal systems ●
Lower Priority	• Inability to monitor proper integration of energy systems within the building envelope (leaks, water or air) • Lack of verification and validation techniques for measuring devices • Limited ability for real-time performance monitoring for control of energy systems • Lack of methods of test to evaluate various storage technologies/materials • Inadequate/nonexistent guidelines on how to evaluate whether a PV warranty claim is justified after being installed 20-30 years • No simplified test methods to credit appliances/equipment that respond to utility power demand signals or offer energy-efficient features (e.g., better humidity control)

E. Priorities for Measurement Science

Some of the most important measurement barriers and challenges described in Table III-2 were further refined and combined into a set of priority topics for measurement science needed for onsite energy generation in buildings. These are summarized below, and described in more detail in Exhibits III.1 to III.10.

Methods for evaluating annual energy production: Onsite generation technology such as photovoltaics (PV) and micro-combined heat and power (CHP) is emerging for use in buildings. The performance of these systems must be evaluated in practical applications using standard test methods and predictive methodologies.

Representative thermal and electrical profiles: Thermal and electrical profile data is needed to quantify the space conditioning, hot water, and plug loads for existing buildings. Using these data in conjunction with energy models would permit improved predictions of building energy performance.

Integrated predictive tools for generation and use: Energy generation and use varies with onsite conditions; widespread acceptance depends on evaluation of the benefits, which cannot be accomplished with current tools.

Methods of data collection and minimum data set: Standard communications devices for equipment, smart appliances, and other systems will be enabled via better data sets. These sets would create a database for "plug and play" standardization, and provide the basics or information for control.

Develop consistent protocols for measuring and reporting performance results: Improvements to existing diagnosis, testing, and validation methods are needed. These improvements include accurate standards and rating methodologies, and open-protocol, minimum data sets to provide standard optimized reports.

Gap between design and performance commissioning: Higher performance onsite energy production systems are being developed; however, meeting net-zero energy goals depends on whether the actual system performance correlates with design. New methods would identify system problems and take corrective action.

Dynamic in situ performance measurements: The actual performance of energy production system needs to be captured in real time; production needs to be accurately monitored so that proper energy credits are given.

Selection of measurement methods to meet societal needs: There are multiple societal goals related to measurement of net-zero energy buildings and all must be measured and balanced. Measuring the source energy and the carbon impact of renewables and nuclear is a challenge.

Predictive design tools to optimize NZEB strategies: The ability to right-size equipment and maximize return on investment (ROI) by minimizing first costs will accelerate deployment of energy production technologies, supporting net-zero energy buildings by justifying costs.

Standard tariff database: Existing methodology for calculating energy savings is highly variable and subject to manipulation. A standard energy tariff would enable market discounting of savings from onsite energy generation systems, reduce customer uncertainty and perception of risk, and increase marketplace confidence.

Exhibit III.1. On-Site Energy Production Measurement Priority
Methods for Evaluating Annual Energy Production

Scope
Renewable and on-site generation for new and existing commercial and residential buildings

Technology Innovation or Improvement

On-site generation technology (e.g., PV, micro-combined heat and power) is emerging as an important approach for achieving net-zero energy buildings. To enable greater use of on-site generation in buildings, the performance of these systems must be evaluated using standard test methods. This will reduce technical and economic risk by demonstrating the performance of the technology in real world applications and enabling validation of predictive performance models.

Measurement Science Challenges and Potential Solutions

Challenges

- Lack of appropriate test methods
- Insufficient data for predictive performance models

Potential Solutions

- Testing and evaluation of available equipment under simulated use conditions
- Field-testing of on-site energy production equipment
- Development of appropriate test methods

Stakeholders and Roles

Government	coordination; funding
National Laboratories . . .	simulated use testing; test method development
Industry	field testing
Standards Organizations . .	formalize test methodologies

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*********
Enhances Competitiveness	*****
Provides Societal Benefits	*****
Supports a Healthy Environment	*****

Exhibit III.2. On-Site Energy Production Measurement Priority
Representative Thermal and Electrical Profiles

Scope
Lighting/cooling equipment/water heating/heating equipment/plug loads/appliances for new and existing commercial and residential buildings

Technology Innovation or Improvement

Data on the space conditioning, hot water and plug loads for existing buildings, when combined with computer simulation models, allows a more comprehensive prediction of the building's energy performance. Load data is essential for evaluation of on-site generation, particularly combined heat and power (CHP), which requires detailed thermal and electrical profiles. Improved thermal and electrical load profiles would enable better sizing, selection, and evaluation of on-site generation systems and help define appropriate operating strategies.

Measurement Science Challenges and Potential Solutions

Challenges

- Non-existent data
- Establishing a representative building model for evaluation
- Actual electrical/thermal loads often significantly greater than that supplied to models

Potential Solutions

- Statistical study of well monitored representative buildings

Stakeholders and Roles

Government	coordination; funding
National Laboratories . . .	data-gathering
Industry	utility participation in building selection and data gathering

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*****
Accelerates Innovation	*********
Enhances Competitiveness	*****
Provides Societal Benefits	*****
Supports a Healthy Environment	*****

Exhibit III.3. On-Site Energy Production Measurement Priority
Integrated Predictive Tools for Energy Generation And Use

Scope
Renewable and on-site generation for new and existing commercial and residential buildings

Technology Innovation or Improvement

Widespread acceptance of on-site generation technology depends on evaluation of benefits which cannot be accomplished with current predictive tools. Both energy generation and use vary widely with on-site conditions; energy can also be used on-site or the excess can be returned to the grid. As a result, predicting the benefits of integrated generation systems can be complex and requires understanding of multiple parameters.

Measurement Science Challenges and Potential Solutions

Challenges

- Descriptive models of equipment
- Representative thermal/electrical use data
- Accepted metric to quantify the benefits

Potential Solutions

- Testing and evaluation of available equipment to establish models
- Development of representative data through evaluation of sample building sets
- Validation of predictive tools

Stakeholders and Roles

Government	coordination; funding
National Laboratories . . .	develop models; gather data
Industry	develop and validate representative equipment
Standards Organizations . .	develop metrics, formalize rating methodology

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*********
Enhances Competitiveness	*****
Provides Societal Benefits	*****
Supports a Healthy Environment	*****

Exhibit III.4. On-Site Energy Production Measurement Priority
Data Collection Devices to Support On-site Generation

Scope
Integration of lighting/cooling equipment/water heating/heating equipment with on-site generation in new and existing commercial and residential buildings

Technology Innovation or Improvement

Addition of standard communications devices to equipment during manufacture (e.g., smart appliances and space conditioning equipment) or retrofit of existing equipment would enable better integration of on-site generation systems. Data sets created from communications devices would provide basic information to better understand energy use and enable more accurate generation systems monitoring and control.

Measurement Science Challenges and Potential Solutions

Challenges
- Cost
- Devices or products not available
- Lack of standard acquisition systems, databases, and certification protocols

Potential Solutions
- Low cost sensing devices
- Data storage systems
- Data transmission devices

Stakeholders and Roles

Government	research funding
National Laboratories . . .	provide tests and certification standards
Industry	develop new devices and sensors
Private Research Institutes	establish databases and communications standards
Standards Organizations . .	provide testing and calibration devices
Trade Groups	set standards
Academia	provide database for communications

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	*****
Provides Societal Benefits	***
Supports a Healthy Environment	*****

Exhibit III.5. On-Site Energy Production Measurement Priority
Protocols for Measuring and Reporting Performance Results

Scope
Lighting/water heating/heating equipment/photovoltaics and other on-generation for new and existing commercial and residential buildings

Technology Innovation or Improvement

Improvements to existing diagnosis, testing, and validation methods are needed to measure and report on the performance of on-site generation. This includes accurate standards and rating methodologies, and open protocols to support standard, optimized reports. These are essential to support effective system service and maintenance and to monitor integrated system use, productivity and performance. New diagnostic methods would also provide reference data and efficiency improvements through better fault detection.

Measurement Science Challenges and Potential Solutions

Challenges

- Proprietary protocols make it difficult for manufacturers to work together
- Manufacturing cost
- Increased manufacturing complexity

Potential Solutions

- Open protocols
- Inexpensive wireless technology for data collection
- Low-cost data storage

Stakeholders and Roles

Government	fund; organize; disseminate research
National Laboratories . . .	fund; organize; disseminate research
Industry	implement new standards
Private Research Institutes	develop open protocol
Standards Organizations . .	develop standard data sets
Trade Groups	define protocols
Academia	define protocols/tests

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	*****
Provides Societal Benefits	***
Supports a Healthy Environment	***

Exhibit III.6. On-Site Energy Production Measurement Priority
Bridge Gap Between Design & Performance Commissioning

Scope
Renewable on-site generation for new and existing commercial and residential buildings

Technology Innovation or Improvement

High performance on-site energy production systems are being developed and are necessary to achieve net-zero energy buildings. However, meeting the goals for net-zero energy buildings depends on whether the actual performance of the on-site energy generation system meets the design predictions. Tools are needed to accurately predict system performance, as well as identify system problems and enable corrective actions as needed.

Measurement Science Challenges and Potential Solutions

Challenges

- Sensors to monitor system performance
- Models to predict system demand
- Tools to project optimal performance, compare to actual and provide trouble-shooting and diagnostic information

Potential Solutions

- Low-cost sensor technology
- Predictive performance modeling systems
- Field demonstrations of tools after lab development

Stakeholders and Roles

Government . . . . National Laboratories	measurement protocols, technical assessment, and performance modeling
Industry	develop sensors
Standards Organizations .	ASTM/UL/ASHRAE (advisory)
Trade Groups	Solar/Wind Energy Association (advisory)
Academia	USGBC (advisory)

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*********
Enhances Competitiveness	*********
Provides Societal Benefits	*********
Supports a Healthy Environment	*********

Exhibit III.7. On-Site Energy Production Measurement Priority
Dynamic In-Situ Performance Measurements

Scope
Renewable on-site energy generation for new and existing commercial and residential buildings

Technology Innovation or Improvement

On-site energy generation has the potential to reduce the burden on centralized power plants and enable greater use of distributed generation systems. However, accurate data on the in-situ performance of renewable energy systems (wind, solar, geothermal) is needed to enable more widespread use in buildings. Capturing and accurately monitoring the real-time actual performance of energy production systems will also ensure that proper credits are given toward achieving net-zero energy buildings goals.

Measurement Science Challenges and Potential Solutions

Challenges

Low-cost, durable technology:

- Sensors (module level)
- Wireless communication between sensor and monitoring system
- Ability to measure solar irradiance

Potential Solutions

- Identification and assessment of sensor and communication technologies that may be applicable
- Lab demonstrations and limited field demonstration

Stakeholders and Roles

Government; National Laboratories	measurement protocols; technical assessment; test methods
Industry	develop sensor technology
Private Research Institute	possible involvement
Standards Organizations	ASTM/UL/ASHRAE (advisory)
Trade Groups	Solar/Wind Energy Association (advisory)
Academia	possible involvement

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*********
Enhances Competitiveness	*****
Provides Societal Benefits	*****
Supports a Healthy Environment	*********

Exhibit III.8. On-Site Energy Production Measurement Priority
Selection of Measurement Methods to Meet Societal Needs

Scope
On-site generation for new and existing commercial and residential buildings

Technology Innovation or Improvement
There are multiple societal goals (secure energy supply, quality of life, environmental safety, climate change) related to net-zero energy buildings. Understanding how these are impacted by generation and other technologies depends on accurate measurement. Numerous challenges exist, such as accurately measuring source energy and the carbon impacts of all energy sources. Performance metrics must be measurable, precise, and support societal goals as well as those for net-zero energy buildings.

Measurement Science Challenges and Potential Solutions

Challenges
- Measuring source energy
- Lack of existing accurate methods

Potential Solutions
- Better measurement procedures and methods for carbon and source energy

Stakeholders and Roles

Government	NIST, DOE, NOAA
National Laboratories . . .	NREL
Industry	utilities
Trade Groups	utilities
Standards Organizations . .	performance metrics

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*********
Enhances Competitiveness	**
Provides Societal Benefits	*********
Supports a Healthy Environment	*********

Exhibit III.9. On-Site Energy Production Measurement Priority
Predictive Design Tools to Optimize NZEB Strategies

Scope
New and existing commercial and residential buildings

Technology Innovation or Improvement

The ability to right size equipment and maximize ROI by minimizing first costs will accelerate energy production into the market to support NZEBs into the market by justifying costs. Predictive design tools could ideally optimize building system integration and demonstrate compliance of new systems. Software tools could be combined to perform integrated analysis (i.e., interactive loads, etc.); this includes integrating existing tools and improving algorithms. The user interface should be designed to address the parameters needed to facilitate market acceptance.

Measurement Science Challenges and Potential Solutions

Challenges

- Lack of standard test data
- Integration of existing tools
- Determining reference materials and test methods for the tool

Potential Solutions

- Identifying tools which address all net zero analysis issues
- Validating tools against bench targets, especially those which will establish field validation

Stakeholders and Roles

Government	mandate use of tool on government facilities
National Laboratories . . . . . . Private Research Institutes. .	bench testing; software development
Industry	performance specifications
Standards Organizations . . .	develop/implement labeling system
Trade Groups	training
Academia	educate decision makers; conduct advanced research

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	*********
Provides Societal Benefits	*****
Supports a Healthy Environment	*****

Exhibit III.10. On-Site Energy Production Measurement Priority
Standard Tariff Database

Scope
On-site energy generation systems for new and existing commercial and residential buildings

Technology Innovation or Improvement

The existing methodology for calculating energy savings is highly variable and subject to manipulation. A standard tariff database would enable market discounting of savings from on-site energy systems, particularly photovoltaics, and would reduce customer uncertainty and perception of risk, as well as increase confidence and acceptance in the market place.

Measurement Science Challenges and Potential Solutions

Challenges
- Non-standardized reference data
- Continually changing data sets

Potential Solutions
- Reference data protocols
- Unbiased information model

Stakeholders and Roles

Government	mandate population of database
National Laboratories . . .	develop interfaces with data; maintain database
Industry . . . . Trade Groups	provide data
Academia	develop algorithms database

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*****
Accelerates Innovation	*****
Enhances Competitiveness	*****
Provides Societal Benefits	*********
Supports a Healthy Environment	*****

IV. Intelligent Buildings

Intelligent buildings apply a range of integrated, microprocessor-based measurement and control technologies to improve the building environment and functionality for occupants and tenants while controlling costs. An effective energy management system, for example, minimizes energy use, provides lowest-cost energy, avoids energy waste by managing occupied space, and efficiently uses resources via centralized control and integration of information from different sources. Strategies for energy reduction may include programmed or optimal start/stop of building systems, adaptive controls, and electricity demand limiting; chiller or boiler optimization; optimized energy sourcing; and automated fault detection and diagnostics for building equipment.

This topic area focuses on the technologies and measurement science needs relevant to computerized building systems, controls, sensors, data collection/ management and applications, integration of systems, grid integration, and other technologies needed to support intelligent systems in new and existing buildings.

A. Characteristics of the Future Built Environment

The potential characteristics of future intelligent building are summarized in Table IV-I. It is expected that buildings will become intelligent shelters, which adapt to human occupants and activities, possess the ability to learn from experience, and are operated with a minimum of human involvement. Ultimately, buildings will be able to seek, compare, and learn from the experiences of similar buildings, incorporating efficient practices and predicting the outcomes.

Table IV-I. Intelligent Buildings – Future Built Environment

Intelligent Building Systems

- Buildings are intelligent shelters which adapt and respond to human needs
- Buildings optimize performance to minimize operation costs and energy use, maximize desired occupant conditions, and effectively integrate with the grid
- Buildings learn—they seek and find similar buildings and compare operations performance, learn from past experience, track building activities and occupant preferences and habits, and then interactively predict occupant energy use and needs
- Integration with nearby buildings/communities enables shared resources and net-zero communities
- Sensor-rich systems share information across multiple applications
- Fully integrated, making use of wireless networks
- Information systems are user-friendly and self-diagnostic for unskilled users

Intelligent Building Operations and Maintenance (O&M)

- Building operations will become systems focused and an integral part of building design and management rather than stand-alone service functions
- Buildings are operated and maintained automatically with minimum human involvement
- Operation systems include more ability for interactions with and feedback to occupants
- Buildings are self-aware and able to identify primary maintenance needs
- Smart integration of energy sources/end uses enables lower energy use

B. Critical Technologies

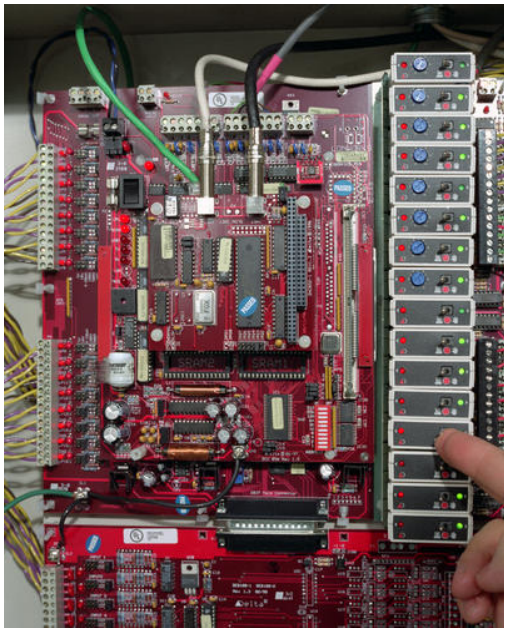
In general, technologies are needed to intelligently define measure, monitor, control, and create an optimal work and living environment in the building. To be readily accepted by occupants and operators, such systems should be user-friendly, have a familiar look and feel, and be enjoyable to use. Technology to facilitate changes in occupant behavior toward greater energy efficiency is essential.

The following is a summary of some specific technologies needed to support the various aspects of intelligent buildings.

Control Systems

Near Term: Intelligent controls are needed to avoid start-up demand spikes and enable a smooth recovery from power failures.

Mid Term: Robust and adaptive control strategies that adjust conditions to occupant activities, and provide simple instructions for manual adjustments will be essential. Building controls should be easy for building operators to use as well as fault-tolerant, self-correcting, and provide different levels of user interaction, but with real-time feedback.



Energy management system at NREL monitors the temperature, humidity, air pressure, duct pressure, light levels, and carbon dioxide levels of a research building and determines the most efficient method for maintaining a comfortable level in the occupied space. (Photo: NREL)

Long Term: Self-configuring distributed control systems (taking out the human factor) should be possible in the long term. One example would be systems that can be "trained" to achieve desired comfort level in the most energy-efficient way, accounting for individual, unique comfort levels. Accurate occupancy detection will enable optimization of energy use (individual and multiple occupants, with identity opt-in, zoning control, or other approaches).

New Sensors

Mid to Long Term: A sustainable/nonproprietary sensor infrastructure would allow many sensor life cycles. Low-cost sensors that enable much more fine-grain monitoring of conditions are needed. In the longer term, self-checking sensors and calibration standards are essential.

Intelligent Models and Feedback Systems

Near Term: Systems that provide information to users through the web and cell phones would provide immediate feedback to inform users and provide incentives for behavioral changes.

Mid Term: Advanced building information models, incorporating machine learning of building behavior and a high-quality user interface, are important for intelligent operations. Predictive models would provide information on the immediate energy and economic impact of occupant actions (statements such as, "Closing that door will cost..." or "Opening this window today will cost…" or queries like, "What can I do to save energy today?" or "Shall I run this device now or later?"). Every device should report or have the capability to poll performance/status information using a non-proprietary standard.

Global Optimization and Systems Integration

Mid Term: Technology is needed to enable whole building global optimization that incorporates multiple factors such as climate, weather, grid conditions, and all building systems. Low-cost, easy-to-use wireless communication for buildings operating under one industry-wide protocol would enable all systems to communicate easily.

Mid to Long Term: Inexpensive, reliable, energy consumption metering for all systems is essential. Electronic standards will define relevant details of appliances, from furnaces to radios, so home energy management systems or models can assimilate and interpret integrated data. Standardized performance and system operation protocols will enable a component/device to communicate criteria to a central supervisory control device. Continuous commissioning and performance diagnostic technologies are essential to support intelligent buildings.

C. Broad Challenges

The broad challenges to development and implementation of intelligent buildings involve both technology limitations and impediments related to human and structural factors.

Technical Challenges

Existing systems for intelligent buildings are too complex to configure and maintain, and are not intuitive. This creates a major challenge to both implementation and use by building operators and occupants. Another key issue is the lack of experience and technology demonstration, which contributes to both technical and investment risk. A related barrier is the current high cost of maintaining low-energy building systems, which are fairly high-tech and complicated for the average building operator.

Collection, management, and interpretation of information present numerous challenges. Information models and standards that capture the measurement and other issues related to intelligent control are lacking. The availability of information in itself is a key barrier. Sensors are not available for obtaining information and there are limited or no methods or standards for data collection and transfer using energy management systems that are suitable for comprehensive modeling. Ancillary to this is the inability to collect and use information to "spotlight" or identify poor performing buildings. Another key limitation is the lack of data on fault frequency and its impact on energy use. *Control systems* are an essential enabling technology in intelligent buildings. Advancement of control system technology is impeded by a lack of dynamic simulation models and robust optimization techniques that work in discontinuous systems.

Non-Technical Challenges

Ownership of building energy use is an overarching challenge. One of the most critical barriers to adoption of intelligent building technology is the disconnection between who makes the initial decision to invest, or not, in the energy-efficient system and who actually pays the cost or reaps the benefits over time. The central issue comes down to determining who actually has ownership of the energy use in a building (e.g., the owner, manager, and occupant).

Privacy concerns and human behavior are an impediment. Utilities, for example, are currently reluctant to share existing data due to privacy issues and are concerned that data could be used to penalize customers. Fundamental understanding about how occupants and buildings interface —which has many complexities based on human behavior—is needed and will most likely require input and study by psychologists or social scientists. To use intelligent systems, consumers may need incentives other than just cost, such as "cool" gadgetry or aesthetics.

D. Measurement Barriers

A number of measurement barriers and challenges were identified that are critical to the development and implementation of intelligent building technologies. These are summarized in Table IV-2 by topical area, with the relative priorities indicated.

Some of the most critical measurement challenges include:

- Data and methods for assessing the performance of buildings,
- Tests and test beds for the evaluation of controls technology and fault detection approaches,
- Best practices guidelines for intelligent design and operation of buildings,
- Measurements to support automation of commissioning processes, and
- Low-cost, reliable energy metering systems.

Table IV-2. Intelligent Buildings – Measurement Barriers and Challenges (● = one vote)	
Data Sharing and Protocols	
High Priority	• Lack of standards for collecting and sharing data ●●●●●● – Standard data format that enables easy sharing of data – Data protocols for all facets of data collection – Lack of standard format for transferring data from systems to analysis tools – Protocols for integrating large quantities of sensor data – Clear data ownership—defined standards and methodologies to control flow of data so building owner can select which data are sent "upstream"

Table IV-2. Intelligent Buildings – Measurement Barriers and Challenges (● = one vote)	
Data Sharing and Protocols (continued)	
Medium Priority	• Lack of protocols to measure equipment performance *in situ* ●● • Data sharing—a universal database for actual energy performance data is not available, and many are unwilling to share data ●●
Lower Priority	• Inability to measure privacy impacts on data, alone or in combination with other data, or in models or predictive tools ● • Lack of buy-in from providers to feed data into database ●
Data Collection and Interpretation	
High Priority	• Challenging data requirements and analysis for assessing building performance, including ●●●●●●●●●●● – Identifying the critical parameters for building design, the accuracy needed, and ways to measure these in real buildings – Gathering a minimal set of data to assess building energy consumption (to within a known accuracy) – Metrics to measure performance (vs. models that use those measures) – Lack of clear definition of how data will be used – Inability to fix what is not understood, i.e., lack of ways to identify the worst performing buildings – Accuracy of sensors to measure inaccurate mechanical systems (e.g., dampers)
Medium Priority	• Lack of analysis tools to mine and interpret data ●●●
Lower Priority	• Lack of effective methods for binning data (e.g., building type, vintage)
Sensors and Control Systems	
High Priority	• High cost of sensors/systems for measuring local consumption of electric power and other energy sources—precludes broad application to systems, equipment, and end users ●●●●●●
Medium Priority	• Difficult to evaluate control strategies due to *in situ* system interactions ●●●
Lower Priority	• Lack of systems integration focus and a centralized control grid/network ● • Difficulty making sensors unobtrusive and integrated into structure or appliances ● • Lack of a comfort sensor and algorithm to capture comfort and calibrate it to different preferences • Difficulty deploying efficient, comprehensive sensor networks and lack of methods for placing sensors to achieve best results • Understanding inputs from fusion of mobile data sources before deploying fixed sensing sources
Models and Simulation	
High Priority	• Limited ability to extract effective model inputs by mining standardized data, including ●●●●● – Data on behavior/use of energy-consuming appliances and demand load on grid – Energy models (linking measurable output to behavior/weather) – Field data to reduce the uncertainty in energy savings (compared to implementation costs) for energy efficiency strategies

Table IV-2. Intelligent Buildings – Measurement Barriers and Challenges
(● = one vote)

Models and Simulation (continued)	
High Priority	– How to measure energy savings (kwh, kw, quads) and relate that to cost of energy (e.g., diverse sources—hydro, natural gas, coal) – Time-consuming aspects of collecting and monitoring data • Simulation tools are lacking and/or existing tools require custom configuration ●●●●
Medium Priority	• Focus of current Building Information Models (BIMs) on design rather than operations and facility maintenance ●●●
Lower Priority	• Lack of interpretive tools that convert data into information useful for building operators and consumers (i.e., actionable information) • Uncertain model validation methods and range of predictive capability (% accuracy)
Intelligent System Performance	
High Priority	• Lack of tools to automate labor-intensive commissioning practices ●●●●●●●●●● – Lack of intelligent techniques applied to building operation problems, from whole buildings to individual components • Inadequate/unavailable test beds and methods of test for evaluation of technology controls and Fault Detection and Diagnosis (FDD) ●●●●●●●●● – Virtual test beds (e.g., to simulate abnormal conditions) – *In situ* evaluation of test bed results under various conditions – Performance benchmarks for comparing control strategies (e.g., more complex than just energy consumption) – Building system performance metrics beyond "net-zero energy" – System level test beds (e.g., Virtual Cybernetic Building Testbed (VCBT)) to test new monitoring and control systems – Test beds to evaluate flow sensing technology (e.g., air, water, etc.) • Insufficient best practice guidelines for "intelligent" system design, operation and maintenance, including ●●●●●●●● – Demonstrating value of added cost to obtain data – Lack of reliable data on cost-effectiveness of measures and designs for specific climate zones/regions – Ability to integrate available forecasted weather data and responsiveness to actual or anticipated conditions
Medium Priority	• Dependence on external factors, such as the grid; and challenges associated with time dependence of energy use, power factors ●●●
Lower Priority	• Limited ability to determine measurement quality (e.g., via virtual sensor) ● • Lack of codes and reinforcement to calibrate/maintain sensors • Limited capability to effectively use wireless technology to collect useful information • Challenges with addressing existing (not new) building stock • Lack of capabilities to develop and implement reliability measures • Lack of smart components that communicate status/performance reliability, cost, and needs

E. Priorities for Measurement Science

Some of the most important measurement barriers and challenges described in Table IV-2 were further refined and combined into a set of priority topics for measurement science needed to support intelligent buildings. These are summarized below, and described in more detail in Figures IV.1 to IV.6.

Extracting effective model inputs by mining standardized data: Current lack of uniformity in energy-saving metrics (e.g., kilowatt-hours, $) makes it difficult to quantify energy savings for efficiency strategies.

Automated tools for commissioning (Cx): Automated Cx of equipment (components), subsystems, and systems can improve performance and lower costs. Tools that automate single or multiple phases of Cx (design, construction, performance, testing, correction, and documentation) are needed.

Test beds for developing and evaluating NZEB technology: A "cyber infrastructure" (such as that of the Network for Earthquake Engineering Simulation (NEES)) is needed to support physical, virtual, and hybrid test beds for intelligent building technologies. This would speed up and standardize evaluation and validation, provide a basis of comparison, and reduce need for duplicative test beds.

Data requirements and analysis methods to assess building performance: Performance assessment of the building, as opposed to just individual components or subsystems, is desirable. Data analysis methods will enable resolution of design intent versus actual building performance.

Standards for collecting and sharing data: No mechanism exists today for data sharing, and a standard for collection of operational data is lacking, limiting comparison and analysis of data.

Best practice guidelines for intelligent system design, operation, and maintenance: Instrumentation, test methods, standard protocols, and best practices will enable development of algorithms that are responsive to exterior sources (actual/forecasted weather conditions) and internal sources (occupancy sensors, thermostat, IEQ, illumination level) using intelligence (e.g., learning behaviors, use patterns).

Exhibit IV.1. Intelligent Buildings Measurement Priority
Extracting Effective Model Inputs by Mining Standardized Data

Scope
All intelligent systems for new and existing commercial and residential buildings

Technology Innovation or Improvement
There is currently a lack of uniformity in metrics used to quantity and monitor energy savings in buildings (e.g., kWh, dollars saved). Uniform data would provide consistent input to energy efficiency strategies and improve the reliability of models used to predict energy savings. Both are essential to determining the performance of net-zero energy buildings. Models are needed to incorporate both external and human (i.e., non-energy) parameters, such as weather and behavior patterns.

Measurement Science Challenges and Potential Solutions

Challenges
- Variations in cost and energy source
- Need to collect cost data along with measurement data in real time

Potential Solutions
- Standardized data collection methods
- Data analysis protocols

Stakeholders and Roles

Government	funding for mission-oriented programs
National Laboratories Industry Private Research Institutes Academia	model development
Standards Organizations	writing standards, arbitration for final decision-making
Trade Groups	aggregate data from industry

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	***
Enhances Competitiveness	*********
Provides Societal Benefits	*****
Supports a Healthy Environment	*****

Exhibit IV.2. Intelligent Buildings Measurement Priority
Automated Tools for Commissioning (Cx)

Scope
New and existing commercial and residential buildings

Technology Innovation or Improvement
There is a lack of automated commissioning (Cx) of equipment (components, subsystems, and systems) in today's buildings. Automation would improve performance (productivity, energy, and comfort), lower labor costs, and enable continuous Cx and the associated benefits. Tools that automate single or multiple phases of Cx (design, construction, performance, testing, correction, documentation), as well as tools specific to building systems (e.g., lighting, HVAC, water), are needed.

Measurement Science Challenges and Potential Solutions

Challenges
- Data identification, collection, and analysis
- Automated fault detection and diagnostics (FDD), and corrective tools

Potential Solutions
- Case studies of individual systems and components
- Test beds for testing and developing tools/approaches
- Models, methods, algorithms, and tools for automated FDD

Stakeholders and Roles

Government	funding, coordination, policy, direct research, codes
National Laboratories Private Research Institutes	applied research, development and demonstration
Industry	product innovation, testing and demonstration
Trade Groups	standard algorithms, best practice guidelines
Standards Organizations	standardization, information dissemination, training
Academia	fundamental and applied research, model validation

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*********
Enhances Competitiveness	*********
Provides Societal Benefits	*********
Supports a Healthy Environment	*****

Exhibit IV.3. Intelligent Buildings Measurement Priority
Test Beds for Developing and Evaluating NZE Technologies

Scope
All intelligent systems for new and existing commercial and residential buildings

Technology Innovation or Improvement
There is a lack of test bed infrastructure for developing and evaluating NZEB technology. A NEES-like cyber infrastructure to support physical, virtual, and hybrid test beds would help speed up and standardize evaluation and validation, provide bases of comparison, and reduce duplication of effort. The infrastructure should include concepts of modularity and reuse-ability, standardized details, methods for tests and test beds that enable evaluation of different technologies, and a third party testing laboratory to do evaluations.

Measurement Science Challenges and Potential Solutions

Challenges
- Unwillingness of owners of resources (databases, software, labs) to share
- Assurance of quality and applicability of test bed elements (data, models)
- Cost and time to establish and maintain the test bed infrastructure

Potential Solutions
- Specify the scope and functional requirements of test beds with input from industry
- Define and implement test bed components and their operating parameters
- Achieve stakeholder acceptance

Stakeholders and Roles

Government	requires technologies to be validated in test bed
National Laboratories	participate in development/host test bed
Industry	participate in definition and support development of test methods and test bed itself
Private Research Institutes. . Academia	participate in definition and use of test bed
Trade Groups	generate testing methods to be embodied in test bed
Standards Organizations . . .	support/encourage adoption of test bed usage

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	*****
Provides Societal Benefits	*****
Supports a Healthy Environment	*********

Exhibit IV.4. Intelligent Buildings Measurement Priority
Data Requirements and Analysis Methodologies to Assess Building Performance

Scope
Intelligent systems for all new and existing commercial and residential buildings

Technology Innovation or Improvement

Performance assessment of the building as opposed to just individual components or subsystems is desirable; data analysis methods will enable resolution of design intent versus actual building performance. Numerous parameters should be assessed, including occupant comfort. The information collected is also needed to define performance-based codes and standards that can be applied to intelligent and other building systems.

Measurement Science Challenges and Potential Solutions

Challenges

- Difficulty of defining building-level performance metrics and defining/quantifying subsystems interaction

Potential Solutions

- Representation of building performance and subsystems interactions
- Ranked significance of subsystems interaction
- Standard building information modeling (BIM) platform

Stakeholders and Roles

Government	pre-competitive program; too broad for industry and common approach needed
National Laboratories . . .	program management
Industry . . . . Trade Groups	active participation to assure feasibility, implementation
Standards Organizations . .	assure standard, hierarchical set of integrated standards

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*********
Enhances Competitiveness	--
Provides Societal Benefits	--
Supports a Healthy Environment	*********

Exhibit IV.5. Intelligent Buildings Measurement Priority
Standards for Collecting and Sharing Data

Scope
All intelligent systems for new and existing commercial and residential buildings

Technology Innovation or Improvement

No mechanism exists today for data sharing, and a standard for data collection is lacking, which limits comparison and analysis of data. An enabling pathway is needed to develop standards and protocols for data sharing. This would encourage collaboration on the determination of best practices, accelerate analysis of collected data, and remove barriers to participation in the data collection process.

Measurement Science Challenges and Potential Solutions

Challenges
- Concerns about privacy/ ownership/proprietary issues
- Lack of well-defined usage criteria, needed to protect source
- Suitable, well-defined incentives to participate

Potential Solutions
- Data de-identification from source
- Standards for data collection, sharing, and utilization, developed collaboratively with stakeholders
- Central repository for standardized data with qualified/ controlled access

Stakeholders and Roles

Government	Funding
National Laboratories Industry Private Research Institutes Trade Groups Academia	Data collection and analysis
Standards Organizations	Develop industry-wide standards

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*********
Enhances Competitiveness	***
Provides Societal Benefits	*********
Supports a Healthy Environment	*****

Exhibit IV.6. Intelligent Buildings Measurement Priority
Best Practice Guidelines for Intelligent System Design, Operation and Maintenance

Scope
Monitoring and control systems for new and existing commercial and residential buildings

Technology Innovation or Improvement
Instrumentation, test methods, standard protocols and best practices will enable development of algorithms that are responsive to exterior sources (actual/ forecasted weather conditions) and internal sources (occupancy sensors, thermostat, IEQ, illumination level) using intelligence (e.g., learning behaviors, use patterns). Failures often go undetected and result in significant energy use, impacting as much as ~40% of energy use in buildings. Best practices for FDD can be used to minimize operational costs (routine maintenance and unplanned maintenance) and improve load management.

Measurement Science Challenges and Potential Solutions

Challenges
- Lack of information about sensors (costs, reliability, value added)
- Need for added personnel training to respond to actionable information
- Lack of best practices repository (e.g., AHSRAE) in specific climate zones

Potential Solutions
- Tap into international best practices
- Establish a central repository for exchange of solution ideas
- Link to tested and evaluation platforms and standard protocol for data exchange

Stakeholders and Roles

Government	Establish central repository of information
National Laboratories . . .	Serve as the link between investors and industry
Industry	Active involvement in testing and implementation
Trade Groups	Provide training and information dissemination
Standards Organizations . .	Supply standard data protocol
Academia	Develop algorithms
Other non-profits	Contribute to best practices
International	International Energy Agency, Japanese (SHASE)

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	*********
Provides Societal Benefits	*****
Supports a Healthy Environment	*********

V. Whole Buildings

The Whole Building concept views the building as a system, rather than a collection of subsystems and components, and provides a broad, integrated perspective of overall building performance, including energy consumption. Viewing the building as a system allows full integration of energy management and other building processes, enabling better overall building performance.

This topic area focused on identifying the technologies and measurement science needs relevant to a whole building energy indicator, assessment, and projection of energy performance including simulation models, intelligent design, systems integration, modeling and model validation, and other relevant systems and tools. Also addressed were indoor air quality control technologies that may enable energy savings, such as heat-recovery ventilation, novel ventilation concepts, and approaches to reducing outdoor air requirements, such as filtration, air cleaning, and low-emitting materials. Technologies applicable to both new and existing buildings were considered. .

A. Characteristics of the Future Built Environment

The potential characteristics of future whole buildings are summarized in Table V-1. Anticipated designs of whole building concepts begin with greater collaboration between the architects, engineers, and contractors in the planning phases. Ultimately, whole buildings will be designed with seamless integration of components into a single system that reduces energy consumption while maintaining occupant comfort and productivity.

Table V-1. Whole Buildings – Future Built Environment
Whole Building Design
• Changes in the initial stage of design lead to more communication between architect, engineer, and contractor. • Climate-specific solutions are utilized to take advantage of the local environment; i.e., Denver offers different opportunities than Miami • Buildings integrate passive cooling, cross-ventilation, and alternative technologies • Different technologies work together to save energy while maintaining focus on human comfort and increased satisfaction • Future performance metrics will focus on people, without needing to account for energy
Whole Building Systems
• Buildings perform as designed without losses due to single malfunctioning components • Buildings are designed and operated to minimize source energy use and emissions • An energy-producing building that goes beyond net-zero can operate off the grid or provide surplus back to the grid • Occupants work efficiently, as the whole building meets telecommunication needs • Occupants can understand the energy implications of various decisions and actions

B. Critical Technologies

A wide variety of technologies will be combined to produce an integrated whole building design. These developments will range from major redesigns in the basic architecture and building envelope to minor, ongoing improvements in each subsystem.

Whole Building Design

Near Term: A redesign of the whole building development process may be needed to adapt to a continuously changing landscape. For example, better understanding of the requirements for integrating onsite renewable energy and their impact on design is needed. Effective quality systems to improve designs and allow buildings to perform as designed are also necessary.

Mid Term: Optimized design (i.e., window and wall, overhang) using software tools and new design software accounting for integrated building physics would allow a better combination of architecture and engineering. Different "plans of attack" for different types and sizes of buildings are needed in order to move toward net-zero. Systems and tools for multi-zoned homes (i.e., insulated partition walls, different comfort levels, and variable temperature supply) leverage the unified system necessary for the whole building.

Performance Assessment

Near Term: Feedback between design-building and construction-performance identifies failures in practice. Architectural and engineering processes need to be more closely aligned for quality improvements in analysis and data. New technology (e.g., in-home dashboard) must be user-friendly with an intuitive system interface. Improved energy simulation software for entire buildings will also help with performance assessment in the near term.

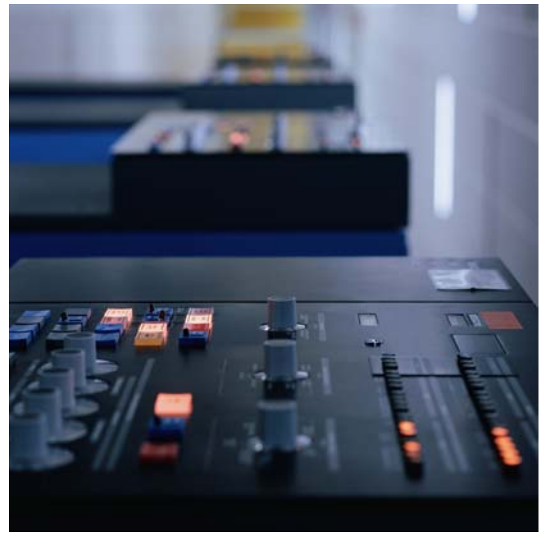
Mid Term: Publicly available databases with building, energy, and occupant data that allow for analysis of larger trends in performance are essential. Standardized guidelines for "house doctors" working to reduce energy use in existing buildings will accelerate the transition to whole building approaches. Increased standardization of building subsystems would produce less "one-off" construction. Energy modeler certification ensures accurate performance assessments.

Long Term: Life cycle thinking—for both cost and environmental impact—is needed to ascertain long-term performance. Operator-independent building controls allow for automated assessment and optimization, as do equipment self-diagnostics and self-commissioning of performance in real time. Performance-based rating and labeling at the building scale encourages efficient integration of subsystems.

Controls and Sensors

Near Term: Low-cost, accurate flow measurement technology for monitoring water, gas, and air is needed. Current technology is either accurate but expensive, or cheap but high maintenance. Hybrid measurement/modeling tools would provide fast quantification of total and component energy use.

Mid Term: CO_2, CO, VOC and particulate-sensing needs to be low-cost, accurate, low-maintenance, and wireless. "Micro-sensing"—wireless, low-cost measuring of temperature, RH, etc.—would facilitate automated fault detection, diagnostics, and commissioning for fine-tuning subsystems energy use.



Commercial building systems control panel. (Photo: MS Online)

Long Term: Demand- and performance-based controls for all indoor environmental quality parameters (e.g., light, thermal, indoor air quality (IAQ)) ensure no wasted energy. Expanded use of Building Information Modeling (BIM) allows for more detailed analysis of potential systems. An intuitive, TurboTax-like user-interface for design could form the basis of design metrics—particularly in concept development.

Indoor Air Quality

Mid Term: Passive air-cleaning technologies need to be developed. Individual-based HVAC would reduce energy demand for maintaining air quality. Low-cost self-cleaning filters are also necessary.

Long Term: Whole building IAQ design must be an integral part of the whole building system.

C. Broad Challenges

Technical Challenges

Design and systems integration is a key issue in the implementation of whole building concepts. Lack of integration between design, analysis, and operation is one of the most critical barriers. In general, there is a lack of data, information, and education related to the use of integrated building design. Overly complex design and construction and under-developed quality management systems both contribute to making integration more difficult. The current architectural focus is on space and form, not on human performance—but the integration of both is necessary for effective whole building designs. Lack of user-friendly, detailed models in the design phase is also an impediment. Another major barrier is that building occupants do not account for building life cycle costs because they move frequently.

Building performance monitoring and control is vital to whole building integrated performance and faces a number of challenges. Validation of energy cost savings with real data, not model predictions, is a major barrier. Useful (i.e., measurable, quantitative, and meaningful) criteria for IAQ control is also lacking, making it difficult to efficiently integrate air quality and energy systems. Performance metrics for novel technologies are lacking and could impede implementation of whole building systems where they are major components.

Models are an essential tool for whole building performance monitoring and are challenged by difficulties in linking to existing proprietary tools (non-open source), and the greater complexity and functionality required for simulation of new building technologies. There are also limited modeling tools for HVAC systems and novel technologies.

Standardization is lacking for many necessary test methods, which is a major barrier. In addition, existing building standards are insufficient to support the whole building concept, and current competing standards in some cases are a source of confusion for both consumers and the construction industry.

Retrofit of the existing built environment remains an issue for adopting whole building concepts. For example, retrofitting of existing residential buildings is labor-intensive and requires well-trained individuals. There is also insufficient clear feedback on retrofit performance.

Non-Technical Challenges

Cost and reliability remains a critical issue for whole building systems. There is a perception that cheaper may be more important than better, making cost-effectiveness of new systems is a key issue. Overcoming the first-cost barrier with the buyer is critical; the important message is that the installed cost is higher, but can lead to a lifetime of benefits, including improved comfort and better energy performance. There is also a perceived risk that implementing whole building systems reduces reliability, i.e., more technology increase the potential for failure modes. Occupant performance factors, which could be used to reduce economic risk, are also lacking for use in asset valuations.

Industry cultural and business models can be inherently limiting. A primary challenge is the lack of energy accountability in the construction industry and poor feedback on energy performance. Another major problem is the over-used and sometimes unwarranted claim that buildings are “green,” primarily because there is little oversight on how this is defined. Architects, engineers, contractors, and investors also speak different languages, and finding common ground over paradigm-changing technologies may be difficult. The propensity to avoid change and stick with traditional methods is also a challenge that needs to be overcome.

Consumer perceptions and behavior can create barriers to the use of whole building systems. Consumers are generally unwilling to change behaviors if they believe they might have to sacrifice some comfort or amenities. Overcoming behavioral issues will require more and better information dissemination, increased awareness of benefits, and greater understanding of how new technologies can be used. Legal risk also plays a role, particularly with privacy issues over the potential release of personal information.

Education and training are key factors in deploying innovative new concepts such as whole buildings. Building design-, construction-, and operation-team education is needed. There is inertia in the building industry workforce today in that workers are trained for business-as-usual methods, not new concepts. In addition, a continuing lack of qualified researchers is exacerbated by limited funding for new research projects in this area.

D. Measurement Barriers

A number of measurement barriers and challenges were identified that are critical to the development and implementation of whole buildings integration of energy systems. These are summarized in Table V-2 by topical area, with the relative priorities indicated.

Some of the top measurement challenges include:

- Whole building models with user-friendly interfaces,
- Metrics to assess deteriorating building performance,
- Lack of a fundamental basis for green building codes and standards for building performance and more universal standards for building measurements,
- Building rating systems,
- Affordable, robust systems for instrumentation and data analysis, and
- Accurate and affordable systems for continuous IAQ monitoring, including the determination of what needs to be measured.

Table V-2. Whole Buildings – Measurement Barriers and Challenges (● = one vote)	
Design and Analysis	
High Priority	• Lack of whole building energy and equipment model with "user friendly" interface ●●●●●● • Inadequate equipment ratings to support system modeling or standard models ●●●● • Lack of standards vs. performance maps for equipment ●●●● • Difficulty defining what to measure for indoor environmental quality (IEQ) performance ●●●● • Lack of short-term energy model to determine energy performance overnight ●●●●
Medium Priority	• Limited data visualization capability (turning data into information) ●●● • Lack of real data for real buildings—model calibration, gap analysis, performance targets, and others (BTU/sq ft., etc.) ●●
Lower Priority	• Limits of current predictive tools; these do not provide a single tool for whole design ● • Lack of a technician-friendly house "description" for load/energy calculations (e.g., manual calculation inputs) • Limited ability to incorporate human factors in simulation-probability-based modeling
Sensors	
High Priority	• Lack of an affordable, robust, instrumentation and data analysis package for non-research applications—energy supply/demand, occupancy, IEQ ●●●● • Limited availability of accurate, affordable sensors for continuous monitoring of VOC, PM, CO, and other contaminants for (IAQ) assessment ●●●● • Lack of low-cost wireless technology ●●●●
Medium Priority	• Limited tools to support robust, low-cost variable ventilation systems ●●

Table V-2. Whole Buildings – Measurement Barriers and Challenges (● = one vote)	
Sensors (continued)	
Lower Priority	• Insufficient sensor calibration—periodic or self-calibration ● • Insufficient methods for measurements of quality control of construction—e.g., imbedded sensors in construction materials for feedback on performance ● • Poor reliability of occupancy sensors—accounting for human interference with controls ● • Lack of portable sensors for flu virus, formaldehyde, VOC, other parameters • Relatively high cost of sensor installation, data loggers, labor • Lack of sensors to measure PV cell temperature in operating systems
Building Operations	
High Priority	• Lack of performance deterioration metrics—estimations of whole building, envelope tightness, equipment, and effectiveness of integration ●●●●●●
Medium Priority	• Inadequate capability for uncertainty analysis and methods for measured data ●● • Limited measurement methods for human interaction with the built environment ●●
Lower Priority	• Limited ability to monitor occupant exposures, and lack of biofeedback systems ● • Lack of sensors to detect human perception of indoor environment • Inability to measure equipment interaction in relationship to onsite system-installed performance (e.g., performance of individual HVAC components) • Insufficient thermal capacitance and time constants for passive solar and load-shifting
Standards and Mandates	
High Priority	• Lack of fundamental basis to create green codes, standards, and programs that cover building performance—energy, IAQ, heat transfer ●●●●●● • Limited universal standards/methods of measurement for buildings ●●●●●
Medium Priority	• Lack of consensus on a "mile per gallon" rating for designers, builders, appraisers, realtors, buyers, and occupants—and no consensus on what it should be ●●● • Limited BACnet* protocols and applications for all control parameters ●●● • Lack of standards for embodied energy and recurring embodied energy in buildings ●●●
Lower Priority	• Limited understanding of the energy and economic impacts of carbon trading on building energy investment decisions ● • Complexity in creating new figures of merit that combine energy efficiency with occupant productivity, comfort, and health ● • Lack of risk metrics with regard to sustainability claims, i.e., determining what claims are realistic; no performance probability index for life cycle cost assessments ●

**BACnet - a data communication protocol for building automation and control networks, developed under the auspices of the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE).*

E. Priorities for Measurement Science

Some of the most important measurement barriers and challenges described in Table V-2 were further refined and combined into a set of priority topics for measurement science needed to support whole buildings. These are summarized below, and described in more detail in Figures V.1 to V.6.

Fundamental basis for green codes, standards, and programs: Standards are needed to provide consistency in the definition of "green." Current design metrics do not adequately predict long- and short-term performance, and may even reward poor design decisions.

Equipment ratings that support system modeling and generate performance maps: Effective ratings would support whole-building simulation for design, and enable understanding of regulatory impacts. The perceived certification burden and definition of certification is a challenge.

Accurate, affordable, low-maintenance sensing and measurement technologies: Improved measurement methods would enable better ventilation designs leading to greater occupant productivity, health, and comfort, and energy savings by avoiding over-ventilation.

Whole building energy/environment model with user-friendly interface: Integrating environmental and energy data and metrics within BIM tools would reduce data and input errors. Better input data and a consistent, transportable database are needed, as well as standard data and measurement protocols.

Performance degradation metrics: Measurement protocols for whole building and subsystem performance over time are needed to help maintain peak building performance and support energy efficiency investments. The current lack of understanding of actual building performance is an impediment.

Universal standards/methods for measurement: Similar standards exist that could be combined without comprising quality, which could reduce unnecessary extra testing and costs. These combined standards would require identifying the best of several existing test methods and determining the most important parameters.

Exhibit V.1. Whole Buildings Measurement Priority
Fundamental Basis for Green Codes, Standards, & Programs

Scope
New and existing commercial and residential buildings

Technology Innovation or Improvement

Standards are needed to provide consistency in the definition of "green." Current design metrics do not adequately predict long and short-term performance of new technologies, and may reward poor design decisions. A fundamental basis will provide assurance for expected building performance enhancements and cost savings over the long term, and provide defensible data to banks, appraisers, and other investment entities.

Measurement Science Challenges and Potential Solutions

Challenges

- Increased cost over current methods
- Measurements have multiple parameters that are difficult to integrate
- Metrics are complex due to different geographic markets

Potential Solutions

- Study cost/benefit of new metrics and ratings
- Determine acceptable accuracy of metrics and develop standards using available information

Stakeholders and Roles

Government	provide central coordination; enforcement
National Laboratories Private Research Institutes Academia	conduct non-competitive research
Industry	provide data and market knowledge
Standards Organizations	write standards; serve as arbiter for final decisions
Trade Groups	aggregate data from companies

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*********
Enhances Competitiveness	*****
Provides Societal Benefits	*********
Supports a Healthy Environment	*********

Exhibit V.2. Whole Buildings Measurement Priority
Equipment Ratings that Support System Modeling & Generate Performance Maps

Scope
Any element that has performance that varies with load and ambient conditions in new and existing commercial and residential buildings

Technology Innovation or Improvement

Effective equipment ratings would support whole-building simulation for design, and enable a better understanding of regulatory impacts. The perceived certification burden and definition of certification is a challenge. Better equipment ratings would ultimately enable performance to replace point measurement of "standard" integrated part load values.

Measurement Science Challenges and Potential Solutions

Challenges
- Perception that certification is a burden
- Defining certification elements (e.g., how many)

Potential Solutions
- Define parameters, ranges, number of points (ambient conditions, degradation/ depreciation over time)
- Develop method of test and degradation rating

Stakeholders and Roles

Government	mandate ratings
National Laboratories . . . . . . Academia	develop rating methodology
Industry . . . . Trade Groups	support and participate in development of method
Private Research Institutes. .	conduct independent tests
Standards Organizations . . .	develop applicable standards, certify products
Other	involve electric and gas utilities

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*********
Enhances Competitiveness	*********
Provides Societal Benefits	*********
Supports a Healthy Environment	*****

Exhibit V.3. Whole Buildings Measurement Priority
Accurate, Affordable, Low-Maintenance Sensing & Measurement Technologies

Scope
New and existing commercial and residential buildings

Technology Innovation or Improvement
Current standards for ventilation are based primarily on controlling human comfort and perceived indoor air quality as a function of space type and size. Improved standards and design methods would enable better ventilation designs leading to greater productivity, occupant health and comfort, and energy savings with less over-ventilation. Buildings and systems need to be controlled to serve occupied spaces. Possible benefits include lower emissions from building materials/off-gassing (manufactures pressured to produce lower emission products), new filtration technologies to control levels; and support for continuous commissioning.

Measurement Science Challenges and Potential Solutions

Challenges
- Lack of understanding of limits/ranges moldof safe valve operation (particulates, VOC, , etc.)
- High cost needs to be brought down to "commercial off the shelf" levels
- Lack of adequate occupancy sensors

Potential Solutions
- Develop better occupancy sensors and "better," smaller, cost-effective sensors for VOCs, etc.
- Integrate with building automation systems, including open, standard protocols: BACnet, ZigBee, Modbus, LonWorks, etc.

Stakeholders and Roles

Government	Develop contaminant concentration limits, calibration standards, and guidance on sensor location
National Laboratories . . .	conduct pilot projects (LBNL); coordinate with retailers (NREL)
Industry	validate test data/methods; develop sensors
Private Research Institutes	consider the health aspect—identify organizations to help determine acceptable levels
Standards Organizations . .	include ASHRAE (62.1, others)
Other	include homeowners, building owners and managers

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	*****
Provides Societal Benefits	*****
Supports a Healthy Environment	*********

Exhibit V.4. Whole Buildings Measurement Priority
Whole Building Energy/Environment Model With User-Friendly Interface

Scope
Whole building technologies for new and existing commercial and residential buildings

Technology Innovation or Improvement

Integrating environmental and energy data and metrics within BIM tools would reduce data and input errors. Better input data and a consistent, transportable database are needed, as well as standard data and measurement protocols. An approach that is familiar to consumers but with a high level of utility would give real-time feedback to non-technical audiences; user-friendly interfaces would promote widespread use .

Measurement Science Challenges and Potential Solutions

Challenges
- Lack of leadership to address multi-attribute issue
- Developing a consistent, transportable database
- Improving input data, models that are harmonized and integrated

Potential Solutions
- Multi-disciplinary collaboration
- Validated models, demonstration projects
- Standard data, environmental modeling, and software validation protocols
- Usability testing

Stakeholders and Roles

Government	involve all stakeholders
National Laboratories	
Industry	
Private Research Institutes . .	
Standards Organizations	
Trade Groups	
Academia	

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	*****
Provides Societal Benefits	*********
Supports a Healthy Environment	*********

Exhibit V.5. Whole Buildings Measurement Priority
Performance Degradation Metrics

Scope
New and existing commercial and residential buildings

Technology Innovation or Improvement

Measurement protocols for whole building and subsystem performance over time are needed to help maintain peak building performance, indoor air quality, and support energy efficiency investments. The availability of such data could also provide a basis for regulatory interventions. The current lack of understanding of actual building performance is an impediment.

Measurement Science Challenges and Potential Solutions

Challenges

- Current lack of baseline data and metrics
- Costly methods to collect data
- Diversity of building stock as it relates to usage, climate

Potential Solutions

- Whole building performance degradation metrics
- Indoor air quality degradation metrics
- Longitudinal data

Stakeholders and Roles

Government	support data collection; develop metrics
National Laboratories . . . . Academia	develop metrics
Industry	verify and apply metrics
Private Research Institutes. . .	develop metrics; collect data
Standards Organizations	establish unified methods
Trade Groups	support data collection and verification

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	--
Provides Societal Benefits	*********
Supports a Healthy Environment	*********

Exhibit V.6. Whole Buildings Measurement Priority
Universal Standards/Methods For Measurement

Scope
Whole buildings technologies in new and existing commercial and residential buildings

Technology Innovation or Improvement

Similar standards exist that could be combined without comprising quality, which could reduce unnecessary extra testing and costs. This would require identifying the best of several existing test methods and determining the most important parameters in the standard.

Measurement Science Challenges and Potential Solutions

Challenges

- Determining the best of several existing test methods
- Winnowing down to the core issues: defining what "really matters" in a standard

Potential Solutions

- Defining the differences among standards and determine best choices
- Effective communication among international participants

Stakeholders and Roles

Government	coordinate efforts
Industry	adhere to standards/methods
Standards Organizations . .	key players, can take the lead if background knowledge readily available

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*****
Accelerates Innovation	*********
Enhances Competitiveness	***
Provides Societal Benefits	--
Supports a Healthy Environment	*****

VI. Building Envelope

Building energy consumption can be reduced by a range of improvements to the building envelope. These steps could include, for example: improved designs, construction methods, and inspection techniques to achieve walls, foundations, and roofs with high R-values; improved insulation; high-performance windows and doors; techniques and equipment to allow daylighting while minimizing any extra cooling loads; reductions in air infiltration through tighter envelope design and construction coupled with improved control of ventilation system airflows; and, use of architectural coatings that scatter and reflect UV, visible, and near-infrared radiation to reduce solar gain or that minimize unwanted heat loss to the night sky. Any improvements to the building envelope must take into consideration potential unintended consequences in both durability and indoor air quality.

This topic area focused on the technologies and measurement science needs relevant to reducing building envelope energy loads through a range of approaches for both residential and commercial buildings in both existing and new building construction.

A. Characteristics of the Future Built Environment

A summary of possible next-generation building envelope technologies and materials is shown in Table VI-1. The performance of building envelopes will benefit greatly from the development of thin, affordable, high R-value insulation materials and improved air barriers. Improved installation techniques will minimize errors and allow for enhancing the envelope of new and existing buildings. In addition, there will be increased installation and integration of sensors in the building envelope that monitor the air tightness of the structure.

Table VI-1. Building Envelope – Future Built Environment
Building Design and Construction
• Buildings will be air-tight with ventilation being completely controlled through mechanical means • We will find better ways to economically and practically insulate existing buildings • Builder error will be eliminated—there will be no construction or installation errors to impair energy efficiency • We will have thin insulation materials with high thermal resistance to heat flow
Building Operations and Maintenance (O&M)
• Ventilation is needed to compensate only for products (emissions) of occupants, not products/emission of materials and building—i.e., zero emissions or toxic products/effects from building materials • Buildings will automatically adapt to changing external conditions, not only seasonally but around the clock • Buildings will be able to self-test for air-tightness • Building envelopes will be self-regulating with regard to moisture

B. Critical Technologies

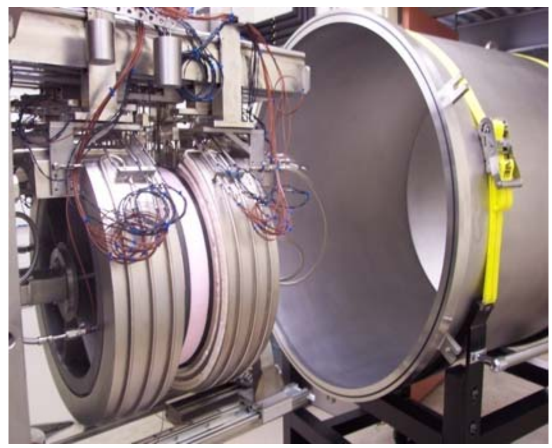
Priority technology advancements needed to enable improvements in the building envelope are listed below.

Building Envelope Technology

Near Term: Assembly-proof envelopes would improve quality and productivity and reduce front-end costs. Advanced lighting systems, including "daylight harvesting," are achievable in the near term. Development of daylighting techniques will minimize HVAC loads and could apply to new construction and retrofits. Defining the building boundary (losses included) and the source and site of energy used will help to structure development of the building envelope.

Mid Term: Integrated PV/flashing systems that roofers can install during re-roofing will reduce costs and build time. Improving enclosure air tightness (including simulations and retrofits) will also reduce costs and improve efficiency.

Long Term: Innovative concepts include electric power generation where PV configurations align with roof shapes (e.g., PV as roof shingles). Efficient glazing of the building envelope could maximize the insulating potential of the walls. Technologies that incorporate heat- and energy-capturing surfaces throughout the building envelope (not just the roof) could be possible in the long term.



NIST's High-Temperature Guarded Hot Plate Apparatus used to measure the thermal conductivity of building and industrial insulation products. (Photo: NIST)

Control Systems

Mid Term: Wireless integration of remote sensors in the envelope that connect to building control systems will aid building performance; improved appearance and interface of technologies will increase marketability.

Materials of Construction

Near Term: The increased market penetration of zero-emission material and rating processes will provide information to designers and builders to promote the use of less bothersome or harmful materials.

Mid Term: Increased development of high R-value, moisture-tolerant, and adaptable building materials will both provide structural integrity and minimize heating and cooling loads. These products include materials such as insulation panels with structural integrity (including phase-change sheetrock that is capable of storing heat and can respond to controls), as well as sheetrock that can provide insulation in the R-30 to R-50 range. There will be greater use of "breathable" membranes and materials that are impervious to outside moisture but enable built up vapor to escape, and windows that change solar gain with the season.

Long Term: Energy efficiency ratings for insulation that allow for identification of diminishing returns based on individual consumer specification should be developed. The insulating properties of windows should increase to R-10 ratings.

Design and Construction Methods

Near and Mid Term: Development of less labor-intensive ways of retrofitting existing building envelopes is needed. Additionally, materials will be designed to integrate together as a system and eliminate time-consuming and costly construction steps.

Long Term: Automated building construction methods and automated installation techniques for envelope components will help to increase quality and minimize variance due to builder/installer competence or error. Design tools are needed that optimize orientation of windows and doors and system specifications to create envelopes that can readily accept solar technologies.

C. Broad Challenges

Technical Challenges

Diagnostic and performance tools are an important element in creating a more efficient envelope. There currently are insufficient diagnostic measurement and identification techniques for energy losses in buildings. The lack of compatibility between current sensors and controls also poses a challenge. Currently, monitoring of the building envelope is very expensive relative to the energy savings. There are also few expense to benefit comparison tools or benchmark standards to aid in decision making. The performance of particular technologies may also be uncertain in specific regions due to climate variations.

Innovative materials have the potential to make building envelopes more efficient, but are hampered in a number of ways. Research on advanced materials (e.g., very high R-value, thin materials) is high-risk, complex and/or nonexistent in some cases. Regarding material emissions, there is a lack of contaminant ratings for multiple reasons, including disagreement on contaminant risks, the perceived cost of ratings, adequate understanding of material emissions over the long term, and other factors. Balancing multiple needs for the same envelope component (e.g., fire, stability, integration with the rest of the building, aesthetics, etc.) can also make materials selection difficult. Lack of R&D funding (public and corporate funding) for materials development is a contributing factor.

Existing building stock is difficult to retrofit and upgrade for various reasons. The non-uniformity of building stock requires builders/installers to start over and develop new solutions for each building. Long lives of buildings suggest that replacement and renovation occur infrequently. Upgrades are often not available in small increments or not advertised as such, making small retrofits unattractive.

Non-Technical Challenges

Industry culture and structure can be an impediment for some envelope solutions. The fragmented nature of the building trades, for example, complicates integrated solutions (e.g., little chance for “plug and play” parts or assemblies for the envelope). The focus of building officials is usually on safety—and often does not extend to energy efficiency or environmental impacts.

Education and training is currently inadequate in this field. A critical barrier is the lack of educated people at all levels (from research and design to installation) to advance the development and deployment of building envelope technology.

Investment incentives are low for some new building envelope technologies. There is a lack of monetary investment to create "low-cost" technology due to the questionable or unclear return on investment for high risk R&D. In the construction industry, builders fear potential liability resulting from new materials or technologies.

D. Measurement Barriers

A number of measurement barriers and challenges were identified that are critical to enabling net-zero energy buildings through an improved building envelope. These barriers and challenges are summarized in Table VI-2 by topical area, with the relative priorities indicated.

Some of the top measurement challenges include:

- Data on materials aging and aging effects on insulation,
- Wireless measurements for building envelope performance and conditions,
- Quantified benefits of thermal upgrades in buildings, and
- Measurement of effects of defects or compromises in the building envelope.

Table VI-2. Building Envelope – Measurement Barriers and Challenges (● = one vote)	
Design and Analysis	
High Priority	• Inadequate measurements of materials aging, particularly the effect of aging on insulation efficiency ●●●●●●
Medium Priority	• Lack of test methods for air barrier systems, and test methods that can be used to evaluate hygrothermal performance and air infiltration of materials and assemblies ●●●
Lower Priority	• Limited integrated predictive tools that enable energy and airflow modeling and have new component add-in capability, for both design and R&D ●● • Lack of data on ground heat loss, especially for highly-insulated foundations and high building density ●● • Insufficient modeling studies and tools for structure-property relationships of foams/web/ composite envelopes (e.g., thermal, mechanical, mass transfer) ● • Lack of measurement methods to assess combined heat, air, and moisture performance of assemblies, for both lab and field use ● • Lack of predictive tools for human comfort (temperature, radiant, air movement, RH) integrated with energy tools, for validation as well as technology development ● • Inadequate hygrothermal balance tools, especially for assessing mold generation versus air tightness over time ●
Sensors	
High Priority	• Lack of capability for wireless measurements (temperature, moisture, hygrothermal) to

Table VI-2. Building Envelope – Measurement Barriers and Challenges (● = one vote)	
	assess both envelope performance and ambient conditions ●●●●
Sensors (continued)	
Lower Priority	• Limited metrics for detecting location of occupants so windows can respond (e.g., with Phase Change Materials) ● • Lack of long-term measurements of moisture in buildings, especially relative to air tightness and insulation, are not available • Lack of sensors to isolate component air leakage under normal operating pressures • Limited capability for multi-layer visualization of temperature and relative humidity in envelope
Building Operations	
High Priority	• Inability to measure effects of defects or compromises in building envelope ●●●●●
Medium Priority	• Limited methods for analyzing energy bills to identify problem houses/specific issues ●●●
Lower Priority	• Limited capability to measure air infiltration on short time intervals to provide input and feedback to other responsive systems (e.g., HVAC, air filtration) ●● • Lack of a monitoring device to detect envelope changes (e.g., degradation of materials, holes in walls, etc.) and methods to assess "damage" of envelope assemblies ●● • Lack of metrics to enable internal conditions (temperature, lighting, occupancy, etc.) and external conditions to drive envelope responsive actions (e.g., air exchange, shutters) • Lack of a low-cost, multi-gas concentration analyzer (especially for emissions from envelope materials) for use in building measurement and control
Standards and Mandates	
Medium Priority	• Insufficient reference materials for multi-component envelope features (e.g., vacuum panels, structural insulation panels) ●●●
Lower Priority	• Lack of a standard method of test for post-occupancy building energy use ● • Insufficient reference materials for optical properties of roofing and other envelope materials, and a method to measure *in situ* • Lack of measurement to support enforcement of current codes (e.g., to ensure that a Home Energy Rating Score (HERS) 40 house is compliant, to support validation and comparative analysis)
Retrofitting	
High Priority	• Insufficient methods for quantifying benefits of thermal upgrades in existing buildings ●●●●●
Medium Priority	• Current satellite data management does not support identification of widespread retrofit opportunities (e.g., infrared scanning linked to Google Earth) ●●●
Lower Priority	• Insufficient methods to determine the best sequence of improvement in retrofits, especially when to seal, when to insulate, when to upgrade equipment (e.g., what sequence of improvements produces the most benefit overall?) ● • Economics of building retrofits and cost- benefits are not established by climate zones • Inadequate co-heating tests to determine building insulation needs for retrofits

E. Priorities for Measurement Science

Some of the most important measurement barriers and challenges described in Table VI-2 were further refined and combined into a set of priority topics for measurement science needed to support building envelopes for net-zero energy buildings. These topics are summarized below, and described in more detail in Figures VI.1 to VI.5.

Wireless temperature and relative humidity transducers with high accuracy, low power, small size, low cost, and long life: The development of wireless temperature and humidity sensors that can be distributed throughout a building and networked to a central control system will enable more finely tuned conditioning and temperature control, thereby maximizing energy savings.

Predicting long-term performance of envelope materials and systems with accelerated aging tests: There are no long-term performance metrics that assess the suitability of different systems and materials under real-life operating conditions. To promote the adoption of these materials and building concepts, measures are needed to assure consumers that the new materials and technologies perform consistently over time, justifying their installation.

Analyzing energy bills to identify retrofit candidate houses: Utility-level data is not currently available that would allow energy use trends to be identified. Developing algorithms and protocols that would index home audit data with actual utility usage would enable more accurate energy audits and decision making about cost-effective retrofits.

In situ measurement of the thermal resistance of existing wall assemblies: There is a need to develop infrared sensing equipment and methodologies that enable onsite testing of the thermal resistance of walls, roofs, and foundations. These techniques can enable identification of buildings that are appropriate for retrofits and can assess the quality of newly constructed or retrofitted envelopes.

Air tightness measurement: There are inadequate standardized test specifications and calibration metrics for assessing the permeability of a building's envelope. This lack of standards prohibits faster and more accurate testing during the construction and use phases. New measurements will ensure an airtight envelope, establish a building benchmark, and make it easier to spot leaks as time progresses.

Exhibit VI.1. Building Envelope Measurement Priority
Wireless Temperature and RH Transducers with High Accuracy, Low Power, Small Size, Low Cost, & Long Life

Scope

Thermal envelope in new and existing commercial and residential buildings

Technology Innovation or Improvement

Wireless transducers will enable more detailed and effective control links between envelope and HVAC, and move buildings closer to maximum conservation operation. This technology also supports automated commissioning and troubleshooting; airtight assemblies; more information on mold conditions; facilitates the use of asymmetric materials; and provides a check value for energy or vapor parameters.

Measurement Science Challenges and Potential Solutions

Challenges

- Size and reliability of RH sensors
- Power use for wireless transmissions
- Lack of common protocol to feed into data management systems

Potential Solutions

- Develop and test instruments
- Build HVAC systems that could be used as control input
- Consider long-term conditioning, perhaps in master specifications

Stakeholders and Roles

Government	provide initial sponsorship
National Laboratories	serve as developers and users
Industry	key roles in cooperative research and commercialization (include in pre-made building components)
Standards Organizations. .	provide communication protocols and accuracy standards
Trade Groups	ensure compatibility
Academia	trial runs

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	***
Provides Societal Benefits	*****
Supports a Healthy Environment	*********

Exhibit VI.2. Building Envelope Measurement Priority
Predicting Long-Term Performance of Envelope Materials and Systems With Accelerated Aging Tests

Scope
Building thermal envelope in existing residential buildings

Technology Innovation or Improvement
There are no long-term performance metrics to assess the suitability of different systems and materials under real-life operating conditions. For these to be marketable, consumers must be assured that they perform consistently over time and justify installation. Improved predictive capability would support better use of daylighting (testing birefringence optical mirrors for degradation, delamination, loss of properties over time); reflective coatings (testing or studying long-term durability and aging properties); mechanically or electrically operated components (long-term durability, e.g., self-operating shutters); and flex duct life (accumulated dirt/reduced air flow over time).

Measurement Science Challenges and Potential Solutions

Challenges
- Physical correlations between measured parameters and service performance
- Long-term performance data on new products
- Test protocols for failure production
- Information on commonalities among established and new products

Potential Solutions
- Define cumulative environmental exposure/conditioning/inputs for multiple failure models (modes, cause, incidences, acceleration modes, life span, performance)
- Facilitate data mining/sharing among labs

Stakeholders and Roles

Government	provide initial sponsorship
National Laboratories . . .	serve as developers and users
Industry	key roles in cooperative research and commercialization (include in pre-made building components)
Standards Organizations . .	formalize methods for consistent industry-wide use
Trade Groups	support data collection, preview new products (voice of the "customer", i.e., include builders & architects)
Other.	FEMP as an early adopter

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*********
Enhances Competitiveness	*********
Provides Societal Benefits	*********
Supports a Healthy Environment	*****

Exhibit VI.3. Building Envelope Measurement Priority
Analyzing Energy Bills to Identify Good Retrofit Candidate Houses

Scope
Existing residential buildings

Technology Innovation or Improvement

The utility-level data are not currently available that would allow energy use trends to be identified. Developing algorithms and protocols which would index home audit data with actual utility usage would enable more accurate energy audits and decision making about cost-effective retrofits. Predictive tools would use a combination of utility records and simulation models, and provide identification of high profile candidate buildings with the most need (most to be gained from retrofit). These tools enable a better match of retrofit resources to needs, and provides more reliable prediction of savings than utility bills or simulation alone.

Measurement Science Challenges and Potential Solutions

Challenges

- Gaining release of utility data
- Acquiring home audit data for simulation
- Streamlining procedures to reduce time required

Potential Solutions

- Algorithms and protocols to index simulation to utility records
- Potentially incorporating smart meters to allow simulations to be validated over short time scales

Stakeholders and Roles

Government	help coordinate
National Laboratories . . .	develop algorithms and methods
Industry	cooperation by utilities needed (billing data)
Academia	contribute and/or lead development
Others	cooperation of homeowners to allow audits

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	*****
Provides Societal Benefits	*********
Supports a Healthy Environment	--

Exhibit VI.4. Building Envelope Measurement Priority
In-Situ Measurement of Thermal Resistance of Existing Wall Assemblies

Scope
Thermal envelope in new and existing commercial and residential buildings

Technology Innovation or Improvement

There is a need to develop sensing equipment and methodologies that enable onsite testing of the thermal resistance of existing envelope assemblies to enable rapid assessments of buildings. This information is typically not known. Measurement methods would allow the identification of buildings that can be retrofitted most cost-effectively

Measurement Science Challenges and Potential Solutions

Challenges

- Lack of process to digitize the image; algorithms to determine thermal resistance from image data and interior-exterior measurements
- Need ability to measure automatically in a short-term test under a wide range of outdoor conditions

Potential Solutions

- Digital analysis of infrared images and heat flux meter for thermal resistance
- Test procedure to compare results with data for known walls
- Database of known conditions, including defects for testing the device

Stakeholders and Roles

Government	assists with coordinating efforts
National Laboratories . . . Industry . . . . Academia	conduct R&D

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	*****
Provides Societal Benefits	*********
Supports a Healthy Environment	--

Exhibit VI.5. Building Envelope Measurement Priority
Air-Tightness Measurement For Envelope Assemblies And Whole Buildings

Scope
Thermal envelope in new and existing commercial and residential buildings

Technology Innovation or Improvement
There are insufficient standardized test specifications and calibration metrics for assessing the permeability of a building's envelope. This lack of standards prohibits faster and more accurate testing during the construction and use phases. More air tightness data will ensure tighter building envelopes, establish a building benchmark, and make it easier to spot leaks as time progresses. They will also enable better understanding of transient material quality, and support development of air barrier systems and building envelope seals to prevent conditioned air leakage. Other benefits include better understanding of transient material quality (e.g., water and air effects) and air barrier systems.

Measurement Science Challenges and Potential Solutions

Challenges
- Scaling up to full-scale application
- Lack of standards for *in situ*, in-progress testing
- Low-cost test that allows repeat testing during construction as well as cyclic testing for artificial aging

Potential Solutions
- Calibrated variable high cfm fans
- Inexpensive airflow sensors, signal processing to remove wind noise, and embedded wireless sensors in thermal and air barrier material
- Measure passive air barrier leakage (ambient pressures)

Stakeholders and Roles

Government	establish performance/testing standards
National Laboratories	develop measurement technologies
Industry	implement and integrate new monitoring technology with products
Private Research Institutes. .	monitor/analyze data and make recommendations for improvement

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	***
Provides Societal Benefits	*********
Supports a Healthy Environment	*****

VII. BUILDING EQUIPMENT

Building system components such as HVAC, lighting, elevators/escalators/moving walkways, computers, and appliances make a significant contribution to overall building energy use. Energy used by these components can be reduced by developing and implementing new technologies, improving existing technologies, or greater use of energy-efficient technologies and practices that are already available. In addition, there are opportunities to reduce energy use in building equipment through integrating technologies, and use of efficient thermal energy recovery and recycle systems. Successful implementation of novel solutions and new building technologies requires measurement science to quantify their energy performance.

This topic area focused on the technologies and measurement science needs relevant to reducing building equipment energy loads in both existing and new building construction. The potential for improving or degrading indoor air quality associated with equipment design decisions and operational strategies for reduced energy consumption is also addressed.

A. Characteristics of the Future Built Environment

The potential characteristics of the future of building equipment are summarized in Table VII-1. In the future, it is expected that building equipment will be integrated in order to monitor the presence and activities of the occupants and use that information to minimize energy usage. Building equipment will operate as a complete system and will be capable of modifying operating characteristics as needed, including the ability to self-detect, diagnose, and notify the building occupants of deviations from optimal performance. Adapting equipment technology to both new construction and retrofitting equipment in old structures will be possible by using standardized connections and reduced equipment size.

Table VII-1. Building Equipment – Future Built Environment
Building Equipment Characteristics
• All equipment will be more efficient • Waste heat from all equipment will be captured and reused either as a thermal resource or for electricity production • Equipment and systems will deliver services when and where needed • All equipment will be “smart” (with onboard diagnostics), user-friendly, capable of remote monitoring/control, and will provide feedback to the user • Consumers will be well-educated about the capabilities and limitations of equipment in their homes and well-motivated to use and maintain it properly, enabling them to make smart choices • Micro-zoning will be the norm and the building systems will automatically adapt to the presence of an individual occupant • The consumer/designer will be able to benchmark the performance of a building against similar homes and lifestyles • Equipment will be easily adapted into existing structures through the use of common connections and by reducing its size

B. Critical Technologies

More energy efficient building equipment technologies are needed in order to achieve NZEB. All aspects of both the building equipment and the owner/operator interface need to be addressed. Equipment must be smaller, easily installed in retrofits, and have the ability to adjust automatically to changing conditions. A summary of some of the specific technologies needed to support increased building equipment efficiency follows.

Controls and Sensors

Near Term: Inexpensive, reliable, long-life wireless sensors and transmitters that are easy to use are needed for more effective equipment communication and data collection.

Mid Term: Fault Detection and Diagnostics is essential for all equipment, along with novel ways of notifying the operator. In addition to notifying the operator of a potential fault, the equipment will be able to "look forward" and adjust settings based on future events, including weather, occupant lifestyle, and energy cost fluctuations.

Long Term: Ability to access the building environment and monitor equipment conditions remotely is needed. Access should be available for a variety of devices (e.g. televisions, smart phones, dedicated devices) and should be affordable and accessible for all income levels.

HVAC

Near Term: Standardized control algorithms for all HVAC equipment are needed to make the installation, maintenance, and operation more seamless for installers. Operators will be continually challenged by equipment that is more complex as the technology progresses. There is greater likelihood of achieving the desired outcome by standardizing as much of the installation process as possible.

Mid Term: Cost-effective, personalized HVAC equipment that is modular for each person could be a reality. The HVAC system would modify its settings based on the presence and preference of the individual occupant.

Long Term: A thermo-electric heat pump with a high coefficient of performance in a smaller size with no moving parts should be developed. Nanolubricants will be used as a means of improving efficiency of new and existing chillers.

Electrical Systems

Near Term: Increased efficiency through better electrical systems designs will be possible. Home and office equipment should reduce electricity consumption by 75 percent thorough better "sleep" functions.

Mid Term: More DC bus-driven equipment with improved plug load supply systems is needed; this will enable the elimination of rectification losses caused by voltage drops and self-correction.

Thermal and Electrical Interchange

Long Term: Equipment to provide for thermal and electrical interchange between neighboring tenants (floor to floor and side to side) is an innovative long-term strategy. When one unit is too warm, the heat can be redirected to the other unit to balance the thermal load. If electrical storage capacity has been reached in one unit, the electrical charging capacity can be redirected.

Design and Economic Models

Near Term: Better design tools are essential for practitioners to accurately size building equipment based on the structure type and lifestyle of the inhabitants. Architects, engineers, and other designers need to match the appropriate equipment with the intended use, structure, and needs of the inhabitants of a building.

Mid Term: Simple economic models that interface with real-time and time-averaged data would allow practitioners and consumers to examine "what if" scenarios. The designer or consumer should be able to evaluate quickly and easily the effectiveness of a variety of different heat pumps or appliances if there is an opportunity to replace them with a different model.

Energy-efficient lighting illuminates the solar-powered Virginia Tech house during the U.S. Department of Energy Solar Decathlon in Washington, D.C. (Photo: NREL)

Water Use Systems

Near Term: Inexpensive, reliable, automatic toilet and lavatory leak sensor. Non-invasive leak detection is important where the building inhabitants may not be able to monitor leaks readily.

Mid Term: High-efficiency point-of-use water heaters (both gas and electric) would enable reduction in the energy associated with water use.

Mid to Long Term: Better thermal energy storage characteristics are needed in water system equipment, including integrated phase-change materials and thermal lag management. One significant improvement that would result is a decrease in the lag time for hot water to arrive at the faucet.

Operations and Maintenance (O&M)

Mid Term: Tools, sensors, and analytical techniques are essential to enable automated commissioning of the building and associated equipment. To synchronize the building equipment to operate at the greatest efficiency, the equipment must work as a system.

Long Term: Building equipment should be self-calibrating, -adjusting, and -optimizing. Minimal interaction from the user would be ideal. Since equipment performance can degrade over time due to a variety of factors, the ability to self-optimize and recalibrate when necessary is an important component in long-term energy efficiency.

Metering

Near Term: Water and gas meters for each end use that are small, inexpensive, easy to install, easy to use, and non-invasive are an important technology. Point-of-service meters will be critical for monitoring individual components.

Long Term: Separately metered HVAC components are needed to monitor each aspect of the unit (e.g. fans, compressor, pump, and coil).

C. Broad Challenges

The broad challenges to developing and improving building equipment are centered on high capital costs and technical impediments. In order to encourage widespread integration of the equipment, these challenges will need to be overcome.

Technical Challenges

Compatibility of equipment is a major challenge. Incorporating a wide variety of equipment into a new building will require the systems to work together as efficiently as possible. Currently, progress is hampered by conflicting commercial interests in information protocols, interoperability standards, and interchangeability standards. When more than one company holds a market share, there can be a conflict with varying communication protocols. There is also a large amount of existing building stock that must be retrofitted with high efficiency equipment. The new equipment may be phased in as older equipment is replaced and the integration of a full system of equipment may take many years.

Collection, management, and interpretation of information present numerous challenges. User-friendly interface and controls on equipment are virtually nonexistent. Consumers must have a way of simply monitoring the performance of the equipment and operators need concise information related to the technical aspects of the equipment to repair it or monitor performance. The lack of consensus on data communication protocols has lead to a diverse set of potential solutions that may not be compatible.

Uniform Technical Standards are needed to determine the true performance of equipment. The standards will allow equipment to be compared on an "apples-to-apples" basis. New resources are needed to optimize proper engineering of the equipment, including expanded ratings to ensure that the equipment is sized correctly for the intended use and occupant needs.

Non-Technical Challenges

High capital costs associated with the purchase and installation of high efficiency equipment prohibits many consumers from taking full advantage of existing equipment improvements. The lack of incentives plus the long payback period associated with the equipment can be barriers to deployment. This can be true especially in low-income areas where energy efficiency is usually worse. Parity in equipment installations must be achieved across all income levels to provide for the greatest market penetration and highest desired effect.

Workforce education is also an impediment. The current state of the building industry is fragmented and there is a lack of communication between technology sectors due to "component thinking" rather than "system thinking." Changing the current practice of commissioning will take educating the installers and operators of the equipment. There is a need to develop a more educated workforce with high-efficiency equipment expertise to install and maintain the equipment. The training will need to occur in nearly every trade, and continuing education will be required since the equipment is continually evolving.

D. Measurement Barriers

A number of measurement barriers and challenges were identified that are critical to the development and implementation of building equipment technologies. These are summarized in Table VII-2 by topical area, with the relative priorities indicated.

Some of the most critical measurement challenges include:

- Data and methods for assessing the performance of buildings,
- Tests and test beds for the evaluation of technology controls and fault detection,
- Measurements to support automation of commissioning processes,
- Best practices guidelines for intelligent design and operation of buildings, and
- Lack of low-cost, reliable energy metering systems.

Table VII-2. Building Equipment – Measurement Barriers and Challenges (● = one vote)	
Test Procedures and Performance Data	
High Priority	• Inadequate test procedures/methods to account for operation in NZEB, including ●●●●●●● - Net-zero performance evaluation standards - Single test method/descriptor for small and large water heaters (energy input) that is real-world representative - Updated method of test for performance rating of heat pumps and central air conditioners (NZEB's operating hours occur at more extreme conditions) - Method of test for performance rating integrated heat pumps • Limited real-time performance information vs. expected performance (FDD) ●●●●●●● • Insufficient measures of the characteristics of the distribution systems related to air and heat movement (ducts) as well as hot water lag; and competing definitions of what constitutes duct leaks and envelope leaks ●●●●●
Medium Priority	• Limited studies of alternative HFC refrigerant systems and heat transfer ●●● • Lack of heat transfer and cooling/heating system COP measurements to determine nanolubricants with best efficiency improvements ●●● • Limited ability to assess part load performance of equipment (e.g., HVAC) vs. rating conditions ●
Lower	• Lack of standard methods of reporting performance data from the field in real-life

Table VII-2. Building Equipment – Measurement Barriers and Challenges (● = one vote)	
Priority	conditions and standards for performance reporting between OEMs; transient behavior and steady-state conditions must be evaluated • Limited ability to measure the performance of adsorptive filtration media • Limited ability to measure the total benefit of natural ventilation (ventilation rate is not sufficient and is very difficult to measure)
Tools and Sensors	
High Priority	• Lack of automated commissioning tools for HVAC equipment ●●●● • Lack of low-cost, easily-installed, high-resolution water and gas measuring sensors and methods ●●● - Should be installed on every device with the ability to report to a central database
Medium Priority	• Insufficient indoor air quality measuring tools, including ● - Lack of real time environmental measurements of VOCs, nanoparticles, etc. - Insufficiencies in current "marker" contaminant methods - Lack of air quality monitoring capabilities for new equipment installations (new systems can create air quality problems)
Lower Priority	• Lack of occupant real-time monitoring and predicting sensors, with the following capabilities - Baselines and rating systems for occupants based on similar characteristics - Modeling of behavior, with a "learning" capacity - Benchmarking against similar homes • Lack of accurate, repeatable, time-efficient air flow tools (measuring ducts, envelope, registers, etc.) • Inadequate methods/sensors for monitoring refrigerant charge—both initial charge and during operation • Limited ability to detect frost on the heat pump and adjust defrost operation
Models and Predictive Data	
Medium Priority	• Lack of information related to existing simulation codes vs. real-world data, to aid in validating and creating better predictive models ●●● • Lack of simple predictive tools for both effective operation and maintenance and for the selection of new equipment by consumers or designers ●●●
Lower Priority	• Limited performance prediction capabilities, such as ●● - Pre-calculated suite of occupant behavioral tools - Optimization of equipment for net-zero energy operation using measurand data
Standards and Protocols	
Medium Priority	• Lack of a fact-based open wireless protocol ●● - Numerous proprietary efforts are underway but standardization is lacking • Reducing the cost of incremental efficiency improvements of systems and equipment ●

E. Priorities for Measurement Science

Some of the most important measurement barriers and challenges described in Table VII-2 were further refined and combined into a set of priority topics for measurement science needed to support more energy-efficient building equipment. These are summarized below, and described in more detail in Figures VII.1 to VII.4.

Update and develop equipment MOTs and performance rating procedures across the board: There is a lack of established test methods across most net-zero energy building applications. Accurate test methods need to be developed that can establish the appropriate linkages between models, building simulations, and actual usage; this will also promote the convergence of models with real data.

Procedures for rating as-installed distribution effectiveness in buildings: Comprehensive rating criteria for ranking various HVAC and water system designs in order to select the components and specifications. The proper design and installation of these systems is essential for ensuring optimum operation with regard to energy consumption, maintenance costs and frequency, and noise.

Continuous comparative analysis of measured vs. expected performance of HVAC and refrigeration equipment: There is a need to develop accurate and inexpensive fault detection and diagnostic schemes which can measure and map the performance of systems with respect to metrics such as temperature, pressure, humidity, flow rate, and power. This will enable building system operators to ensure that equipment is performing up to its rated specifications and allow changes to be made when performance parameters leave their expected range.

Novel lubrication approaches for efficient thermal systems: Lubrication is a key area where improvements can be made to enhance system efficiency. Oil-free bearings are a case in point. A new generation of lubricants that reduce friction in bearings can also improve the thermal performance of heat exchangers (e.g., nanolubricants).

Exhibit VII.1. Building Equipment Measurement Priority
Update and Develop Equipment Methods of Test (MOTs) & Performance Rating Procedures

Scope

Lighting/cooling equipment/water heating/ heating equipment/plug loads/ appliances in new and existing commercial and residential buildings

Technology Innovation or Improvement

There is a lack of established methods of test (MOTs) across most net-zero energy building applications. The development of accurate test methods can establish the appropriate linkages between models, building simulations, and actual usage; it will also promote the convergence of models with real data. These methods should also be revisited periodically as "actual use" changes as net-zero is approached. Equipment accounts for a large share of building energy use and is an important component of the NZEB strategy. Equipment replacement improves existing building stock, and improved tests will improve these purchase decisions.

Measurement Science Challenges and Potential Solutions

Challenges

- Characterization of "actual use"
- Lack of MOTs/performance ratings for some categories of equipment
- Developing linkage between MOTs/performance ratings and building simulation models

Potential Solutions

- Characterize "actual use" where possible though literature search, experts, and larger-scale field studies as needed
- Create linkage between MOTs/performance ratings &building simulation models

Stakeholders and Roles

Government	provide resources, regulations
National Laboratories	develop data, MOTs/performance rating procedures
Industry . . . . Private Research Institutes. .	provide data, resources, validation
Standards Organizations . . .	develop/support development of standards
Trade Groups	coordinate/mediate/provide voice for industry
Academia	provide future scanning
Other	utilities facilitate field studies/implementation

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	***
Provides Societal Benefits	*********
Supports a Healthy Environment	*****

Exhibit VII.2. Building Equipment Measurement Priority
Procedure for Rating As-Installed Distribution Effectiveness in Buildings

Scope
Cooling equipment/water heating/heating equipment/ ventilation effectiveness in new and existing commercial buildings

Technology Innovation or Improvement
Comprehensive rating criteria for ranking various HVAC and water system designs is needed to select components and specifications. The proper design and installation of these systems is essential for ensuring optimum operation conditions with regard to energy consumption, maintenance costs and frequency, and noise. The design (system configuration, sizing, material selection, etc.) and installation practices (insulation levels, fittings selection, leakiness) have a profound impact on the pressure drop, energy consumption, noise, operating parameters, and maintainability of HVAC and water systems and plumbing systems.

Measurement Science Challenges and Potential Solutions

Challenges
- Lack of modeling tools to characterize different distribution systems in various applications & identify/correct faults
- Standards, procedures, and manuals to ensure design/installation meet requirements

Potential Solutions
- Case studies using a “whole building” test bed to measure various distribution system configurations and performance
- Standard(s) for distribution system losses
- Installation parameters database

Stakeholders and Roles

Government	provide resources, regulations
National Laboratories . . .	develop data & performance rating procedures
Industry . . . . Private Research Institutes	provide data, resources, validation
Standards Organizations . .	develop/support development of standards
Trade Groups	coordinate/mediate/provide voice for industry
Academia	provide future scanning
Other	utilities facilitate field studies/implementation

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	--
Enhances Competitiveness	*****
Provides Societal Benefits	*********
Supports a Healthy Environment	*****

Exhibit VII.3. Building Equipment Measurement Priority
Continuous Comparative Analysis of Measured vs. Expected Performance of HVAC and Refrigeration Equipment

Scope

Heating equipment cooling equipment/water heating/refrigeration in new and existing commercial and residential buildings

Technology Innovation or Improvement

HVAC and refrigeration equipment performance depends on installation, maintenance, commissioning, and monitoring operation procedures; performance can be easily degraded by as much as 20%. There is a need to develop accurate and inexpensive sensors and fault detection and diagnostic (FDD) schemes which can measure and map the performance of systems with respect to metrics such as temperature, pressure, humidity, flow rate, and power. This will enable building system operators to ensure that equipment is performing up to its rated specifications and allow changes to be made when performance parameters leave their expected range.

Measurement Science Challenges and Potential Solutions

Challenges

- Cost and integration of sensors
- Fault detection/diagnostic (FDD) schemes
- Measurement and mapping of system and components

Potential Solutions

- Accurate and inexpensive sensors (temperature, pressure, humidity, flow, power)
- Performance evaluation and FDD schemes
- Intelligent technology and friendly user interface

Stakeholders and Roles

Government	research programs and market incentives
National Laboratories . . . Private Research Institutes Academia	conduct research
Industry	conduct research and training
Standards Organizations . .	harmonize protocols
Trade Groups	promote and provide training

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	*****
Provides Societal Benefits	*********
Supports a Healthy Environment	**

Exhibit VII.4. Building Equipment Measurement Priority
Nanolubricants for Efficient Chillers

Scope
Cooling equipment in new and existing commercial buildings

Technology Innovation or Improvement
Nanolubricants can potentially improve the performance of building chillers and cooling systems. Characterization of nanolubricants is needed to enable selection of those that will provide the best improvement of chiller efficiency. The measurement science is currently not available to characterizes the influence of nanoparticle size, shape, and material on refrigerant/nanolubricant boiling heat transfer.

Measurement Science Challenges and Potential Solutions

Challenges
- Developing a model that characterizes nanolubricants that is based on systematic investigation of the fundamental mechanisms that govern refrigerant/nanolubricant boiling

Potential Solutions
- Create a flexible experimental design to determine specific nanoparticles (size and material) and concentration
- Conduct pool boiling tests to establish performance of R134a mixed with base lubricant and systematically selected nanolubricants

Stakeholders and Roles
Government	provide coordination
National Laboratories	conduct evaluations and measurements
Academia.	validate measurements
Industry . . . . Trade Groups	evaluate performance in chillers
Private Research Institutes. .	validate data in the lab and field

RELATIVE IMPACTS	Low High
Improves Energy Efficiency	*********
Accelerates Innovation	*****
Enhances Competitiveness	*********
Provides Societal Benefits	*********
Supports a Healthy Environment	--

Appendices

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APPENDIX C: ACRONYMS

ANSI: American National Standards Institute

ASHRAE: American Society of Heating, Refrigerating and Air Conditioning Engineers

ASTM: ASTM International

BACnet: ANSI/ASHRAE Standard 135, Data Communication Protocol for Building Automation and Control Networks

BIM: Building Information Model

BTU: British Thermal Unit

cfm: cubic feet per minute

cx: commissioning

CHP: Combined Heat and Power

CO: carbon monoxide

CO2: carbon dioxide

COP: coefficient of performance

DOE: Department of Energy

FDD: Fault Detection and Diagnostics

FEMP: Federal Energy Management Program

GSHP: geothermal ground source heat pumps

HERS: Home Energy Rating Score

HFC: hydrofluorocarbon

HVAC: Heating, ventilation, and air conditioning system

IAQ: Indoor air quality

IEQ: Indoor environmental quality that encompasses all aspects of the indoor environment including air quality, thermal comfort, lighting, and noise.

kWh: kilowatt hour

LBNL: Lawrence Berkeley National Laboratory

MOT: Methods of test

NEES: Network for Earthquake Engineering

NIST: National Institute for Standards and Technology

NOAA: National Oceanic and Aeronautics Agency

NREL: National Renewable Energy Laboratory

NSTC: National Science and Technology Council

NZE: Net Zero Energy

NZEB: Net-zero energy buildings

O&M: Operation and Maintenance

OEM: Original Equipment Manufacturer

PM: particulate matter

PV: photovoltaic

R&D: Research and Development

RH: relative humidity

ROI: return on investment

SHASE: A major organization for heating, air-conditioning, and sanitary engineering in Japan with a history of over 80 years.

TV: Television

UK: United Kingdom

UL: Underwriters' Laboratory

UN MDGI: United National Millennium Development Goals Indicators

USBBC: U.S. Green Building Council

USGS: U.S. Geological Survey

UV: ultraviolet

VCBT: Virtual Cybernetic Building Testbed

VOC: volatile organic compound