EL Program: Embedded Intelligence in Buildings

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Strategic Goal: Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure

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Summary: Congress has established a national goal of achieving net-zero energy buildings by 2030.[1] Approximately 84% of the life cycle energy use of a building is associated with operating the building rather than the materials and energy used for construction.[2] This program will provide the measurement science to realize energy efficient building operation through integrated cybernetic building systems with distributed, embedded intelligence that can optimize building system performance, detect and respond to faults and operational errors, and enable integration of building systems with smart grid technologies.

DESCRIPTION

Program and Strategic Goal: The Embedded Intelligence in Buildings Program supports the objectives of the Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure Goal.

Objective: To develop and deploy advances in measurement science that will improve building operations to achieve energy efficiency, occupant comfort, and safety through the use of intelligent building systems by 2016.

What is the problem? "The world is facing twin energy related threats: that of not having adequate and secure supplies of energy at affordable prices and that of environmental harm caused by consuming too much of it."[3] Any successful response to these threats must consider buildings. Buildings account for 40% of the United States' energy use and a similar percentage of carbon dioxide emissions, more than the transportation or industrial sectors.[4] Emissions associated with buildings and appliances are projected to grow faster than those from any other sector.[5] In order to ensure adequate supplies of energy and to curtail the projected growth of CO_2 emissions, it is essential that building energy consumption be significantly reduced. Congress has established a national goal of achieving net-zero energy buildings by 2030.[1]

Approximately 84% of the life cycle energy use of a building is associated with operating the building rather than the materials and energy used for construction.[2] "Building systems almost never achieve their design efficiencies at any time during building operation and their performance typically degrades over time."[6] As the Nation proceeds with developing a new smart grid and increasing the use of intermittent renewable energy sources, buildings occupants will need access to actionable energy consumption information and building systems will need to become collaborative partners in maintaining the stability and reliability of the grid.

In addition to energy issues, building operation practices face pressure to improve safety, security, and occupant comfort and health. Building control companies, equipment and system manufacturers, energy providers, utilities, and design engineers are under increasing pressure to improve performance and reduce costs by developing building systems that integrate more and more building services, including energy management, fire and security, vertical transportation, fault detection and diagnostics, optimal control, the real time purchase of electricity, and the aggregation of building stock. Measurement science is lacking to enable these systems to have the intelligence to communicate, interact, share information, make decisions, detect and respond to faults, and perform in a synergistic and reliable manner. Specific needs include standard data models, communication protocols, user interface standards, security procedures, testing tools, and performance metrics. Overcoming these barriers is critical if building systems are to meet these operational needs and if the U.S. is to obtain a significant share of the developing world wide market for such systems.

Why is it hard to solve? Buildings are complex systems of interacting subsystems. Most commercial buildings are "one off" designs with unique operating needs. Interactions between subsystems can be complex and are often not well understood. The industry is very sensitive to first cost of new technologies and performance goals such as energy efficiency, indoor air quality, and comfort often conflict. There are no simulation tools that can realistically capture

all of the necessary details of complex interacting building systems. Past improvements in the capabilities of building automation systems have not resulted in the expected reductions in overall building energy consumption or improvement in occupant comfort.[7]

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

How is it solved today, and by whom? The measurement science problems that inhibit development and effective deployment of integrated intelligent building systems have not been solved. However, there has been progress in some areas. As a result of past NIST leadership, the BACnet standard has been created and adopted by over 30 countries and most HVAC control system manufacturers. Conformance testing tools and processes have been developed and industry run certification programs are in place. This provides an effective base upon which to build more comprehensive solutions.

There are related efforts to improve building energy performance. The U.S. Department of Energy focuses on development and demonstration of energy technologies. The European Union is promoting building energy efficiency through a directive that requires efficiency improvements through a combination of education, financial incentives, and mandatory performance targets. In the U.S. efforts to improve building energy efficiency have been promoted by the Green Building Council. The International Energy Agency sponsored research programs to advance the state of building commissioning. None of these efforts, however, address the underlying measurement science needs.

Why NIST? This program is closely aligned with the EL mission to promote U.S. innovation and competitiveness by anticipating and meeting the measurement science, standards, and technology needs of the U.S. building industry. It builds on the EL core competencies of Energy Efficient and Intelligent Operation of Buildings with Healthy Indoor Environments, and Intelligent Sensing, Control Processes, and Automation for Cyber-Physical Systems. It also aligns with our strategic goal of Sustainable and Energy-Efficient Manufacturing, Materials, and Infrastructure.

Because a mismatch exists between who invests (manufacturers) and who benefits (public and other end users), public sector involvement is necessary to overcome the initial barrier of developing the measurement science. EL is in a position to leverage its strong ties to industry stakeholders, academia, and standards organizations. EL has the needed technical expertise and an international reputation for excellence in the technical areas relevant to cybernetic building systems[8] as a result of over two decades of technical work and collaboration. EL staff has leadership positions on the key U.S. and international committees that will make use of the program results.

What is the new technical idea? The new idea is to address the measurement science needs of cybernetic building systems in a holistic, integrated manner that considers complex system interactions and their impact on energy consumption, comfort, safety, and maintenance. Measurement science is needed that will:

- Lead to enhancements in communication protocol standards that enable the practical use of integrated HVAC, lighting, security, vertical transport, energy management, and emergency response systems to achieve increased comfort, safety, and energy efficiency;
- Be used to create a laboratory testbed capable of whole building emulation of normal operation and a variety of faulty and hazardous conditions suitable for evaluating the needs and performance of cybernetic building systems in identifying and responding to equipment failures and abnormal conditions;
- Enable more energy efficient building operation through development of information models and software tools that improve the design and commissioning process and embedded intelligence in building control systems that can detect and respond to problems and optimize the control and performance of building systems; and
- Enable secure real-time communication of building system information to outside parties such as interconnection of building automation and control systems with a future smart utility grid.

Why can we succeed now? Success is likely because of a combination of factors. There is heightened public recognition that energy security and efficiency is a highly desirable national goal. There have been significant technological advances in microprocessor-based technologies, new and lower cost sensors, and the ability to integrate building control systems. EL staff has the needed expertise and established relationships with key industry stakeholders and relevant professional societies and standards development organizations that will use the results. The Administration has established policies and interagency collaborations that emphasize a government role in improving building operation. Finally, there is already a track record of success from earlier work that has had demonstrable worldwide impact.

What is the research plan? The research plan consists of a portfolio of interrelated projects that focus on key areas of measurement science needed to achieve successful development and implementation of cybernetic building systems. Collectively they provide a comprehensive approach that will lead to new industry standards and practices which will result in a radical market transformation in building system design and operation.

The Smart Building Automation and Control Testbed and Standards project is the cornerstone upon which other aspects of the research program are built. It supports ongoing development and refinement of a unique laboratory facility, the Virtual Cybernetic Building Testbed (VCBT). This realistic, whole-building emulator is used by other projects in the program to conduct research under controlled conditions that cannot be accomplished in actual buildings. This project also provides technical support for the ongoing development of key enabling standards that create the communication infrastructure used in the VCBT and upon which embedded intelligent systems will be built. EL's past work has led to international adoption and commercialization of BACnet, one of the most widely used and successful standards in

ASHRAE history. In FY 2014, EL will continue work with industry partners to enhance BACnet capabilities in ways that eliminate barriers to extending BACnet beyond HVAC applications and enable BACnet systems to provide operational data to enterprise management tools. The core simulation engine for the VCBT will be updated to take advantage of advances in the underlying simulation tools and capabilities to emulate fan-coil terminal units and conduct tests of system-level hierarchical FDD tools will be added.

Commissioning Building Systems for Improved Energy Performance is a project intended to address the problem that building automation systems are rarely commissioned and are poorly maintained, resulting in excessive energy consumption and other operational issues. The commissioning research builds on international collaborations through the International Energy Agency and will focus in FY 2014 on expanding the capabilities of the NIST commissioning tool to include chillers and terminal units. This will include of performance validation from field tests and a new software interface to be called HVAC-Cx.

Two projects address automated fault detection and diagnostics (FDD) for HVAC system components. One focuses on residential systems and one on commercial building systems. Both projects involve developing and testing FDD tools that can be implemented using commercially available instrumentation and control products, and demonstrating the energy benefits of detecting and responding to faults before building conditions degrade to the point that occupants complain. In FY 2014 the work will focus in the residential area on the continuing development of a new test procedure for evaluating the performance of FDD tools for heat pumps and air conditioners. For commercial building systems the work will focus on field testing of a Fault Detection and Diagnostic – Expert Assistant (FDD-EA) and enhancing its capabilities by expanding from equipment-level diagnostics to hierarchical, system-scale detection that can reduce the burden on operators responding to multiple FDD alarms.

A research project on control optimization using intelligent agents seeks to enable a fundamental paradigm shift in the way in which building system operation is optimized for energy efficiency. Classical optimization techniques have not been successful in buildings but adapting intelligent agent technology from other fields offers the promise of significant improvement in building operations. In FY 2014 the work will focus on completing construction of a new laboratory facility for testing intelligent agent-based optimization approaches using real building mechanical equipment, and the refinement and testing of software tools to enable rapid prototyping and screening of candidate intelligent agent optimization algorithms.

Cybernetic building systems involve communication and interaction with entities outside the building as well as within. In FY 2014 the Building Integration with the Smart Grid project will continue improving and expanding consumer access to their energy usage information in the White House Green Button initiative, including sponsorship of a White House Presidential Innovation Fellow starting in June 2013. In addition to Green Button implementation activities, the Building Integration with Smart Grid project will continue activities that support the development of key standards for building-to-grid integration identified in the NIST Smart Grid Roadmap and also conduct research expected to result in new control strategies for managing electrical loads and local generation that can pioneer a new era of real-time

electricity pricing, increased use of renewable energy sources, and building electrical load management that is responsive to needs of the smart grid.

How will teamwork be ensured? The projects that make up the Embedded Intelligence in Buildings Program involve EL staff from multiple divisions and numerous outside partners through CRADAs and established relationships with professional society technical committees and standards committees. Each project has specific plans in place for coordination and information exchange needed to accomplish its goals. These plans include details for internal EL collaborations and also interactions with outside parties. Periodic meetings with project leaders will enable high level coordination and information exchange between project teams.

ACCOMPLISHMENTS and IMPACT

R&D Impact: The Embedded Intelligence in Buildings Program includes research and development efforts designed to achieve impact, in part, through peer-reviewed archival journal publications. The publications listed below have been identified as important for effectively disseminating research results from the program. They include one journal, *ASHRAE Journal*, that has a target audience of practicing professionals and has a world-wide direct impact on their professional practice. The target audience for the other listed journals are researchers. One of the listed journals is too new to have an established impact factor. Because *ASHRAE Journal* focuses on practical applications of research, it is less frequently cited resulting in a very low impact factor. To address these anomalies for program evaluation and tracking purposes, it is proposed that the average impact factor be used for all journals. The choice of journal for publishing will be based primarily on subject matter alignment with the journal audience, with lesser consideration on impact factor.

- **Top Journals:**
  ASHRAE Journal: Impact factor 0.392
  Automation in Construction: Impact factor 1.702
  Energy and Buildings: Impact factor 2.386
  HVAC&R Research: Impact Factor 1.034
  IEEE Transactions on Smart Grid: Impact factor not available because the journal is new
  International Journal of Refrigeration: Impact Factor 2.089

- **Research Outcomes:** A list of ERB-approved publications for the identified archival journals in FY 2013 is provided below as of May 2013, along with the project name in brackets.

  Veronica, D. A. 2013. Automatically Detecting Faulty Regulation in HVAC Controls. HVAC&R Research, Vol. 19, No. 4, 412-422, [Fault Detection and Diagnostics for Commercial Heating, Ventilating, and Air-Conditioning Systems]

  Heo, Payne, Domanski, "Normalized Performance Parameters for a Residential Heat Pump in the Cooling Mode with Single Faults Imposed" [Fault Detection and Diagnostics for Air-Conditioners and Heat Pumps]

- **Potential Research Impacts:** A list of papers accepted for publication in the identified journals but with no realized impact as measured by citations is provided below. The project name and year of acceptance is indicated in brackets.

  Veronica, D. A., Detecting Cooling Coil Fouling Automatically – Part 1: A novel Concept. *HVAC&R Research*, Vol. 16, No. 4, 2010 [Fault Detection and Diagnostics for Commercial Heating, Ventilating, and Air-Conditioning Systems, FY 2010]

  Veronica, D. A., Detecting Cooling Coil Fouling Automatically – Part 2: Results Using a Multilayer Perceptron. *HVAC&R Research*, Vol. 16, No. 5, 2010 [Fault Detection and Diagnostics for Commercial Heating, Ventilating, and Air-Conditioning Systems, FY 2010]

  Holmberg, D.G., "Demand Response and Standards: Enabling a New Role for Buildings in the Smart Grid," *ASHRAE Journal*, Nov. 2011 [Building Integration with Smart Grid, FY 2010]

  Holmberg, D.G., Ghatikar, G., Koch, E.L., Boch, J., "OpenADR Advances," *ASHRAE Journal*, Nov. 2012 [Building Integration with Smart Grid, FY 2011]

  Kelley, G.E. Bushby, S.T. "Are Intelligent Agents the Key to Optimizing Building HVAC System Performance?, *HVAC&R Research,* Vol. 18, Issue 4, 750-759, 2012 [Inteligent Building Agents, FY 2012]

- **Realized Research Impacts:** A list of papers accepted for publication in the identified journals and demonstrating impact through citations is provided below. The project name, year of acceptance and the number of citations is indicated in brackets.

  Schein, J., Bushby S.T. "Fault Detection and Diagnostics for AHUs and VAV Boxes," *ASHRAE Journal* Vol 47 No. 7, July 2005 [Fault Detection and Diagnostics for Commercial Heating, Ventilating, and Air-Conditioning Systems, FY 2005, 5 citations]

  Schein, J., and Bushby, S.T. "A Hierarchical Rule-Based Fault Detection and Diagnostic Method for HVAC Systems," *HVAC&R Research* Vol. 12, No. 1, 2006 [Fault Detection and Diagnostics for Commercial Heating, Ventilating, and Air-Conditioning Systems, FY 2006, 16 citations]

  Schein, J., Bushby, S.T., Castro, N.S. "A Rule-Based Fault Detection Method for Air Handling Units," *Energy & Buildings* Vol. 38, Issue 12, December 2006*, pp. 1485-1492, 2006 [Fault Detection and Diagnostics for Commercial Heating, Ventilating, and Air-Conditioning Systems, FY 2006, 44 citations]

  Song, W.S., Hong, S.H., Bushby, S.T. "A Performance Analysis of BACnet Local Area Networks", *HVAC&R Research*, Vol. 14, Issue 2, March 2008 [Smart Building Automation and Control Testbed and Standards, FY 2008, 3 citations]

Holmberg, D.G, Bushby, S.T. Butler, J.F. "BACnet for Utilities and Metering", *ASHRAE Journal*, Vol 50 No. 4, April 2008 [Building Integration with Smart Grid, FY 2008, 3 citations]

Holmberg, D.G., Bushby, S.T. "BACnet and the Smart Grid", *ASHRAE Journal* Vol. 51 No. 11, November 2009 [Building Integration with Smart Grid, FY 2008, 2 citations]

Kim, Yoon, Payne, Domanski, "Design of a steady-state detector for fault detection and diagnosis of a residential air conditioner", *Int. Jrn. of Refrig.*, Vol. 31, pp. 790-99, 2009. [Fault Detection and Diagnostics for Air-Conditioners and Heat Pumps, FY 2008, 32 citations]

Bushby, S.T., "Information Model Standard for Integrating Facilities with Smart Grid", *ASHRAE Journal* Vol. 53 No. 11, November 2011 [Smart Building Automation and Control Testbed and Standards, FY 2010, 3 citations]

Impact of Standards and Tools:

- **Technology Transfer Outcomes:** Strong engagement with industry partners through standards and tool development is a key method for transferring the results of NIST research in the Embedded Intelligence in Buildings Program to industry. Staff members hold key leadership positions in national and international standards committees with subject areas related to research in this program. Below are select standards, tools, or data sets that have been drafted and/or made available publicly that have potential to achieve broad-based end use arranged by the topic of their potential impact.

  Improved Energy Efficiency of Operations:

  - Cooling and heating mode fault-applied performance data for heat pumps provided to indstry and academia. This well characterized data provides a basis for manufacturers to develop new fault detection products [Fault Detection and Diagnostics for Commercial Heating, Ventilating, and Air-Conditioning Systems, FY 2010].

  - Completed IEA Annex 40, Commissioning of Building HVAC Systems for Improving Energy Performance and IEA Annex 47, Cost Effective Commissioning for Existing and Low Energy Buildings. These international collaborations established benchmark guidance for current commissioning practices and identified key areas were improvement is needed [Commissioning Building Systems for Improved Energy Performance, FY 2010].

  - CITE-AHU tool for automated commissioning of air-handling units. This software tool significantly reduces the workload for commissioning air-handling units increasing the likelihood that this important activity will be more widely adopted [Commissioning Building Systems for Improved Energy Performance, FY 2011].

  - Prototype intelligent building agent simulation tool completed. This tool will be used by researchers to explore the potential impact of this emerging technology [Intelligent Building Agents, FY 2011].

- Rapid prototyping tool developed for investigating FDD algorithms. Rapid prototyping and testing of candidate algorithms will enable researchers to identify the most promising fault detection approaches [Fault Detection and Diagnostics for Commercial Heating, Ventilating, and Air-Conditioning Systems, FY 2011].

- DASH database, a national repository of triple bottom line building performance data enabling the consistent collection of quantitative data about green, sustainable, and high performance buildings and facilitating reporting and analysis based on that information [Commissioning Building Systems for Improved Energy Performance, FY 2013].

- Variations of the Fault Detection and Diagnostics – Expert Assistant (FDD-EA) tool for single-duct air handling units, dual-duct air handling units, variable-air volume boxes, and terminal units incorporated into the California Energy Commission Universal Translator tool [Fault Detection and Diagnostics for Commercial Heating, Ventilating, and Air-Conditioning Systems, FY 2013]

New Integrated Functionality for Building Systems

- Draft ASHRAE/NEMA Facility Smart Grid Information Model standard. This standard, currently under development with NIST technical leadership and using the results on NIST research, will define an information model to represent the information necessary to manage electrical generation and consumption in a home, office building or commercial facility [Building Integration with Smart Grid, FY 2012]

- The OpenADR 2.0 standard has been drafted and is nearing completion. This standard represents an implementation of a subset of OASIS Energy Interoperation (EI) features that specifically relate to demand response (OpenADR refers to Open Automated Demand Response). Demand response in Open ADR 2.0 can be triggered by either price signals or by requests to shed load based on a set of levels. OpenADR 2.0 is a refinement on a previous version that has been used in many field trials in the U.S. and several other countries. It is supported by an industry alliance (OpenADR Alliance) that is beginning interoperability testing of the revised version. Interoperability testing is a necessary first step towards broader implementation. [Building Integration with Smart Grid, FY 2013]

- Smart Energy Profile (SEP) 2.0 has been recently completed and published by the Zigbee Alliance. SEP2.0 is a key standard identified in the NIST framework, covering residential consumer energy communications with devices. [Building Integration with Smart Grid, FY 2013]

Improved Occupant Safety

- A successful demonstration of real-time tactical decision aid displays in an emergency responder field exercise with the Wilson, NC Fire Department [Building Information Exchange with First Responders, FY 2010].

- Developed a new simplified approach to dynamically changing the size and characteristics of the emulated buildings in the VCBT, increasing its utility and reducing set up time [The Virtual Cybernetic Building Testbed, FY 2010].

- **Potential Technology Transfer Impacts:** Below are examples of standards/tools with dissemination and adoption that have the potential to achieve significant broad-based end use.
    - Industry adoption and use of ASTM 2204 Standard Guide for Summarizing the Economic Impacts of Building-Related Projects. This standard, based on NIST measurement science work, is part of a series of 26 standards that promote more cost-effective decisions for the design, construction, and operation of constructed facilities. This type of analysis provides the economic driver for application of all the technologies and practices impacted by the Embedded Intelligence in Buildings Program [Economic Support for BFRL, FY2009, Standard adopted 2011]

    - Published OASIS Energy Market Information Exchange standard (EMIX). EMIX defines an information model representing price and product information intended to serve as the basis for communication protocol standards that will exchange this information [Building Integration with Smart Grid, FY 2012].

    - Published OASIS Energy Interoperation (EI) standard. EI builds on the product information from EMIX and specifies an information model and messages that enable standard communication of: demand response events, electricity prices, market participation bids and offers, and load and generation predictions [Building Integration with Smart Grid, FY 2012].

    - Published NAESB REQ-18/WEG-19 Energy Usage Information Standard defining customer electrical energy usage information for the wholesale and retail electricity market, REQ-21 Energy Service Provider Interface (ESPI) defining a standard communication protocol to convey energy usage information, and REQ-22 Third Party Access to Smart Meter-Based Information. These standards form the basis for the Green Button Download My Data program which today is available to 19 million utility customers and is expected to expand to over 30 million customers in the coming year [Building Integration with Smart Grid, FY 2012 and FY 2013].

    - Green Button Software Development Kit. As described in a February 2013 NIST Techbeat article,[9] NIST has contributed tools to support Green Button implementations and testing and certification programs, as well as web tools (www.greenbuttondata.org) to enable self-testing of the structure of Green Button files. Multiple utilities and vendors have committed to the Green Button initiative and are using NIST Green Button tools to support their implementations. With additional NIST technical support, EPA implemented an upgrade of its Home Energy Yardstick residential evaluation tool to be able to upload Green Button data. [Building Integration with Smart Grid, FY13]

- **Realized Technology Transfer Impacts:** Below are examples of standards or tools that have achieved broad-based end use.

- Adoption of the BACnet standard, based on NIST measurement science work, by CEN, ISO, and over 30 countries [Expansion, Certification and Demonstration of BACnet and Smart Building Automation and Control Testbed and Standards, FY 1996 – FY 2013] .

- Establishment of BACnet International and BACnet Interest Groups in Australasia, Europe, Finland, Middle East, Russia, Sweden [Expansion, Certification and Demonstration of BACnet and Smart Building Automation and Control Testbed and Standards, FY 1996 – FY 2013].

- Implementation of BACnet by over 650 companies including every major HVAC control system manufacturer as the protocol of choice for integrated building automation systems [Expansion, Certification and Demonstration of BACnet and Smart Building Automation and Control Testbed and Standards, FY 1996 – FY 2013].

- Adoption of an Annex F to NFPA 72 covering NEMA SB 30 fire service annunciator displays. This standard provides a uniform interface to aid emergency responders during an incident [Building Information Exchange with First Responders, FY 2010].

- Industry adoption of VPACC and APAR fault detection algorithms for performance monitoring of HVAC products, based on NIST measurement science work, leading to better performing and more energy efficient HVAC systems [Fault Detection and Diagnostics for Commercial Heating, Ventilating, and Air-Conditioning Systems, FY 2006].

- Cooling and heating mode performance data used by commercial developers of residential FDD equipment [Fault Detection and Diagnostics for Air Conditioners and Heat Pumps FY 2011].

Other: In addition to these mechanisms, the Embedded Intelligence in Buildings Program has been using CRADAs with building automation system manufacturers and a university facilities department as a way to transfer the results of NIST research and to speed the development of commercial products and increase market demand based on that research.

Recognition of EL:
- A Department of Commerce Gold Medal;
- A National Performance Review "Hammer Award;"
- A Department of Commerce Bronze Medal;
- William P. Schlicter Award;
- Edward Bennet Rosa Award;
- Special citations and Distinguished Service Award from ASHRAE; and
- BACnet International Fellow.

Examples of recent positive media coverage include:

"NIST Targets Energy Apps with Green Button Tools" InformationWeek, February 2013, coverage of new User Guide to NIST Green Button Software Development Kit.

"Connecting buildings to the Smart Grid - Engineers should know the NIST and ASHRAE standards for the Smart Grid, and be aware of the availability of Smart Grid-ready products for commercial buildings." Consulting-Specifying Engineer, December 2012, coverage of several NIST smart grid standardization efforts.

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[1] *Energy Independence and Security Act of 2007*
[2] *World Business Council EEB Report*
http://www.wbcsd.org/DocRoot/seqH6hKIxVrTRYxAhemY/EEBSummaryReportFINAL.pdf, p. 11
[3] *IEA's World Energy Outlook, http://www.iea.org/Textbase/npsum/WEO2006SUM.pdf*
[4] *DOE Buildings Energy Data Book http://buildingsdatabook.eren.doe.gov/*
[5] Reducing *U. S. Greenhouse Gas Emissions:How Much at What Cost?http://www.mckinsey.com/clientservice/ccsi/pdf/US_ghg_final_report.pdf*
[6] *Federal Research and Development Agenda for Net-Aero Energy, High-Performance Green Buildings*, NSTC Report, October, 2008
[7] Turner, C. and M. Frankel. 2008. "Energy Performance of LEED for New Construction Buildings. U.S. Green Building Council.
[8] A Cybernetic Building System integrates building automation and control systems for energy management, fire detection, security and vertical transport systems. It also integrates the building systems with outside service providers and utilities.
[9] "New Guide Will Allow Electric Utilities to Develop Green Button Web Tools," NIST Tech Beat (February 6, 2013), available at http://www.nist.gov/el/button-020613.cfm