2009 BFRL Project Description

Project Title: Energy Monitoring System for Net Zero-Energy Buildings

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Co-Investigator(s):

BFRL Program: Healthy and Sustainable Buildings

Objective: To develop the measurement science to provide real time energy data for various end uses within buildings and develop methods of test to evaluate energy monitoring technologies.

Problem:

What is the problem? A major challenge in assessing the effectiveness of energy conservation measures in buildings is conveying real-time information about energy consumption by particular end-use to occupants. The World Business Council for Sustainable Development identified "Lack of awareness and information on energy consumption and cost" as one of three major barriers to energy efficient behavior and reports that "technical devices to measure energy consumption and provide immediate feedback help households to cut energy consumption by as much as 20%."[1] The U.N.'s Intergovernmental Panel on Climate Change stated that "infrequent meter readings provide insufficient feedback to consumers on their energy use and on the potential impact of their efficiency investments."[2] A monitoring system is needed that can provide the energy consumption of various devices/systems in a building in both real time and for user selected time intervals without undue complexity, cost, and installation issues.

Why is it hard to solve? The development of measurement systems that provide real-time feedback to building occupants regarding energy consumption is hard to solve because of the need to minimize cost and installation complexity. To achieve these goals, accuracy may need to be sacrificed. Increased levels of uncertainty in the determination of energy end uses, however, may still result in systems that provide effective feedback to help occupants reduce energy consumption. While the relationship between behavior and the degree of uncertainty in the measurements will not be the focus of this work, the development of those uncertainty estimates will be a critical component of it. The development of those uncertainty estimates for the optimized systems is extremely challenging considering the nearly infinite variety of potential energy use patterns in buildings.

How is it solved today, and by whom? No work has been found that uses advanced measurement concepts to produce a complete information system that provides real-time data on

[1] World Business Council for Sustainable Development, Energy Efficiency in Buildings,2007.
[2] United Nations Intergovernmental Panel on Climate Change, Climate Change 2007: Mitigation.

energy consumption in a building. Commercial products are available, but they are rather costly (on the order of several thousand dollars). It is evident that a different measurement paradigm is needed to achieve lower price levels. Research was recently sponsored by ASHRAE to attempt to disaggregate end uses of hot water by analyzing water temperature and flow signatures obtained at the water heater[3]. Researchers at MIT[4] and Concordia University[5] have also carried out similar studies to determine end uses of electricity by analyzing electrical signals, but no recent work has been uncovered. No work has been found that attempts to correlate measured energy consumption with outdoor weather conditions.

Why NIST? The proposed work will enhance U.S. competitiveness by developing the measurement science for low-cost products that will enable reduced energy consumption in buildings. The project fits in the Measurement Science for Net Zero Energy, High-Performance Buildings Strategic Priority Area by providing the fundamental science to provide real-time feedback on energy consumption. Because the project will attempt to develop new measurement science that will enable low-cost and easily-applied measurements, BFRL is the appropriate organization to tackle this project considering its mission to develop the critical measurement science for the building industry.

Approach:

What is the new technical idea? To develop a system that will allow for real-time reporting of energy consumption by end-use, NIST proposes to develop the measurement science that will provide the information while minimizing the number of sensing points in a building. The ideal situation would be one in which the data from a single meter can be analyzed to determine end uses. The feasibility of such an approach will be investigated, although it is realized that multiple sensing points may be unavoidable to provide an adequate level of confidence in the information. One aspect of this work will involve an exploration of signal analysis techniques that will identify characteristic signatures of the energy consumption of devices. For example, a particular appliance may have a characteristic signal when it is powered up, or the frequency of energy use from it may identify the source of electricity consumption. The single measurements may require augmentation by distributed sensors at specific end uses to train the system or to permanently report data. Possibilities may also exist to correlate energy consumption with outdoor and indoor conditions to identify energy use by heating and cooling equipment. The optimization of the sensor system to minimize the number of sensing points while still providing useful information to occupants will be explored. The objective function for this optimization may involve measures of both the uncertainty in energy measurements as well as economic metrics such as the installed cost. NIST will explore the resulting measurement uncertainty as the number of sensors varies to allow potential users of the measurement system to decide upon an appropriate level of uncertainty for their application.

Comment [T1]: I can't see how multiple sensing points can be avoided, especially since the requirements are so different as one moves from one zone or application to another.

[3] Tiller, Henze, Goepfert, and Guo 2004, "Domestic Hot Water End Use Analysis Methods and Preliminary Results" ASHRAE Transactions.

[4] Hart, Nonintrusive Appliance Load Monitor Published References, http://www.georgehart.com/research/nalmrefs.html

[5] Farinaccio and Zmeureanu 1999, "Using a pattern recognition approach to disaggregate the total electricity consumption in a house into the major end-uses" Energy and Buildings vol. 30, no 3.

Why can we succeed now? The key reason why we can succeed in developing low-cost energy monitoring systems at this point is the availability of wireless sensor hardware and software. Wireless technology will allow for easy installation of sensors by avoiding the need to run signal wire throughout a building. This technology eases the experimental research and will permit inconspicuous installation of any necessary sensors that are part of the final measurement system.

What is the research plan? To explore the measurement science needs for developing low-cost and easily installed energy monitoring systems in buildings, an initial effort will be undertaken to review existing technology and literature to assess the state of the energy monitoring industry. The key questions to be investigated include the following:

1. What studies exist on energy savings that result when occupants have more detailed information on energy consumption, and are there any unwanted side effects of such systems (e.g. an occupant realizes that a certain action results in low energy costs so he carries out that action more often)?
2. What commercial products are available to monitor energy consumption in commercial and residential buildings and what is the cost of those products?
3. What research has been undertaken to disaggregate electricity, gas, and water consumption by end use to provide the user detailed information on energy consumption?
4. What specifications are available to determine the necessary number of sensors to provide a complete representation of the energy consumption in a building?
5. What sensor technologies are available or under development that will decrease the cost and difficulty in installing monitoring systems in buildings?
6. What critical measurement science needs must be addressed to make energy information systems readily available to homeowners and building owners?

NIST will use the results of this assessment to focus on the critical measurement issues that will be investigated in future years. Effort will be undertaken to further evolve the signal processing techniques to disaggregate electricity consumption by end uses. Formal optimization routines will be applied to the measurement problem to provide guidance on deploying an electrical energy monitoring system at the lowest cost and effort. This guidance will serve as the ultimate output of the effort. Upon completing the research to guide the use of monitoring systems for electricity, NIST will explore the use of the SBIR or other outreach programs to move the measurement methods into commercial products. Future work could optimize the measurement of natural gas, heating oil, and water consumption in a building should there prove a need.

Recent Results: New project

Standards and Codes: none