NILM Applications for the Energy-Efficient Home

Dane Christensen†
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
dane.christensen@nrel.gov

Lieko Earle
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
lieko.earle@nrel.gov

Bethany Sparn
National Renewable Energy Laboratory
15013 Denver West Parkway
Golden, CO 80401
bethany.sparn@nrel.gov

ABSTRACT

Research in non-intrusive load monitoring (NILM) has exploded in recent years, enabling innovative and significant technological advances. Few products are yet available, but development is underway at universities and corporations worldwide. In this presentation we discuss our vision of how these products will enable energy efficiency, improve comfort, and provide positive cash flow in the U.S. housing sector. Specifically, we forecast products that serve the greater systems – the energy management, whole-house, and community energy systems.

Keywords

Efficiency, Residential, AHEM, Energy Management, Analysis, Fault Detection, Diagnostics, Measurement, Load Disaggregation

1. INTRODUCTION

The National Renewable Energy Laboratory's (NREL) Residential Buildings Group serves as technical lead to the U.S. Department of Energy's Building America program[1], the nation's leading research effort for systems integration delivering residential building energy efficiency. The program's research innovations have enabled builders to achieve cost-effective energy savings in excess of 60% relative to circa-1995 code construction.

As built-in efficiency opportunities have been leveraged, energy consumption by lighting, electronics, and "other" end-uses – most of which the designer/builder can neither control nor effectively predict – has surpassed every other category and now accounts for roughly 40% of electricity costs in U.S. homes[2]. That proportion is forecasted to grow for the foreseeable future. To meet the nation's energy needs, these diverse and complex energy uses must be moderated. Reducing these loads is challenging because they are poorly understood, unmonitored, and uncontrolled.

In this presentation, we discuss the immediate and near-term applications where we predict NILM's greatest impact will be achieved, and identify other opportunities where NILM will enable systems innovations. NILM technologies promise to deliver valuable data on what, when, and how end-uses are consuming energy. To create "killer apps" based on these data, you must first determine who will use them and why.

2. CONSIDER THE CUSTOMERS

Potential customers for a residential NILM application include:

- The homeowner or building manager, who is using energy and has various motivations for seeking out a NILM application;
- The technology sector, which will incorporate NILM technology into an existing or new product;
- The service sector, which will use NILM tools to deliver home maintenance, retrofits, advertising, or security services; and
- The utility, which sells the energy and receives regulatory incentives to cost-effectively implement efficiency.

A residential application built on NILM will serve one or more of these customers and will meet that customer's specific needs.

3. DEFINE THE NEEDS

3.1 Homeowner Needs

Homeowners do not know where their energy "goes" – i.e., how, when, and why their devices, lighting, and appliances are using energy[3]. They are similarly naïve about the savings potential and comfort enhancements available from usage and retrofit changes[4]. Homeowners struggle to maintain appliances, and have very limited tools to manage their energy use, costs, and comfort.

3.2 Technology Sector Needs

The technology sector is devising many uses for NILM output that deliver features and lifestyle enhancements. Many companies are entering this sector, typically seeking to add NILM features into existing mobility, security, audiovisual, and comfort product lines. Because of business sector silos, the broader applications of NILM have not been fully realized. There is no standard for NILM data and data access, so each company is using proprietary formats for its products.

3.3 Service Sector Needs

The service sector is challenged with legacy audit and analysis methods[5]. Many small businesses with thin profit margins struggle to guarantee value and savings to their customers. Larger companies also struggle to maintain high-quality service. Overall, few technologies exist to support process improvement.

3.4 Utility Needs

Because of the regulatory environment and a highly diverse residential customer base, utilities have limited tools to effectively deliver residential energy savings and peak reductions. They actively seek new tools to reduce the cost and duration of efficiency pilots, and have difficulty demonstrating that efficiency programs have saved energy[6]. Utilities are challenged to generate sufficient energy during peak consumption hours and to maintain grid stability at acceptable costs.

4. MEET THE NEEDS

Many products can be devised with these diverse needs, goals, and interests in mind. The most successful and innovative will be designed to simultaneously meet needs of multiple stakeholders. An example is a NILM system built into a utility meter to verify demand response. This meter provides added value by making data available to the homeowner's energy management devices. Technology manufacturers could build products around that data stream and service technicians could access it for diagnostic purposes. Although this example appears to meet most customer needs, it represents an "infrastructure" application, which is a slow path to market for NILM.

Alternatively, NILM can be packaged as a standalone consumer product. Early market products have not been widely successful for several reasons – primarily cost and installation requirements. Although market analysis would be necessary for a given product, we expect products that cost a few hundred dollars or less, and can be installed very simply, have a higher chance of being adopted.

From a systems perspective, NILM applications should deliver both energy savings (with associated cost savings) and non-energy lifestyle benefits. Our research focuses on energy savings and energy-related lifestyle benefits such as thermal comfort, indoor air quality, lighting, maintenance, and building durability.

5. NEAR-TERM APPLICATIONS

We expect NILM products entering the market in the next 3–5 years will be targeted largely at specific individual needs.

Feedback on energy consumption, with device-level breakdown, is a clear opportunity. Studies show that visualization alone has minimal effect on persistence[7]. Yet these products are likely to educate customers and lay a foundation for later efficiency product opportunities.

Use of NILM by utilities to verify specific device-level performance as part of an efficiency program is a key opportunity. NILM will allow the impact of the new technology on other household systems, and on occupant use, to be measured more effectively, quickly, and cheaply than current methods permit. Measuring the persistence of energy savings is a significant issue.

Thermostats have traditionally operated as open-loop devices. Manufacturers such as Nest, Honeywell, and Trane/iLink have recently incorporated networking and novel decision-making techniques; however they do not predict in advance of the load. If NILM allowed a thermostat to see that all the lights, the entertainment center, the oven, and the refrigerator turned on, the air conditioner could turn on in advance of the temperature rising, and the system could direct cooling to occupied rooms, thus delivering substantial savings and better comfort.

Utilities struggle to maintain power delivery during the hottest hours of the year, because of high air conditioning demand. During times of very low demand (mild winter nights), utilities cannot throttle generating stations enough, so they must dump energy into large resistor banks. Both “load shed” and “load add” needs present an opportunity for smart home controls, enabled by NILM. By knowing a home’s typical usage by device, an energy management system can perform device-specific demand response much more effectively. Many utilities provide incentives for demand response, a trend that will certainly grow.

6. LONG-TERM APPLICATIONS

Highly advanced whole-house control systems are possible, but current designs require placement of numerous sensors throughout the house. NILM is a key enabling technology to improving these products. The near-term opportunity of device modulation to meet utility cost incentives will transition into a toolkit for automating whole-house energy use, cost, and comfort. Additional features (security, audiovisual) will likely be incorporated into successful automated home energy management (AHEM) products, to become a class of home automation systems.

NILM-based analysis can identify poor appliance performance. Fault detection and diagnostics (FDD) based on runtimes, event and operational signatures, and energy consumption trends will also begin to incorporate prognostics (FDD/P). Applications will then be able to forecast imminent problems, deliver maintenance reminders, and identify when professional service is needed.

Similar to equipment-focused FDD/P, NILM can also be used as a continuous home audit. Currently, audits provide a snapshot-in-time view of the building asset, and cannot account for occupant usage effects. Applications using NILM to suggest cost-effective retrofits or consumer goods replacement, to enhance federal, local and utility rebate programs, and to monitor for significant building changes, are most likely to find a strong market.

Finally, the cost to install an electric vehicle charging station is nearly prohibitive, and many utilities are beginning to charge a different rate for electric vehicle charging, thus requiring a second meter. Both utilities and homeowners will benefit from applications that use NILM to submeter this and similar emerging products.

7. CONCLUSION

The future for NILM is very bright, and a system-level view of application design will maximize its impact and accelerate its market adoption. NILM is expected to have a significant impact on our energy economy by enabling energy efficiency, utility cost savings, and other non-energy benefits.

8. REFERENCES

[1] http://www.buildingamerica.gov

[2] Buildings Energy Data Book 2010, Table 2.1.6.

[3] Ehrhardt-Martinez, K (2009) *Pursuing Energy-Efficient Behavior in a Regulatory Environment: Motivating Contexts for Policymakers, Program Administrators, and Program Implementers*. Prepared for the California Public Utilities Commission. Washington, DC.

[4] Attari SZ, DeKay ML, Davidson CI, de Bruin WB (2010) *Public perceptions of energy consumption and savings*. Proc Natl Acad Sci USA 107:16054–16059.

[5] Bianchi M (2011) *Technical Barriers, Gaps, and Opportunities Related to Home Energy Upgrade Market Delivery*. NREL Report No. TP-5500-53011.

[6] See, for example, *BPA FY13 Technology Innovation FOA, Topic 5* at: https://www.bpa.gov/SECURE/TIFO/

[7] Ehrhardt-Martinez K, Donnelly KA, Laitner JA (2010) *Advanced Metering Initiatives and Residential Feedback Programs: A Meta-Review for Household Electricity-Saving Opportunities*. Washington, DC: ACEEE.

ABOUT THE AUTHORS:

Dane Christensen directs the laboratory program and facilities for NREL’s Residential Building Group. His research efforts and interests include HVAC, hot water, building envelopes, demand response, and AHEM. Dane supports technical efforts for the Building America program and related energy efficiency initiatives. Dane received a PhD in mechanical engineering from University of California, Berkeley and a BS in mechanical engineering from Rice University.

Lieko Earle leads field testing efforts for Building America and conducts laboratory- and field-based research on automated home energy management devices and control strategies. Her interests include advanced monitoring efforts such as real-time energy-use feedback for occupants and non-intrusive load-disaggregation techniques. Lieko received a PhD in physics from University of Colorado and a Sc.B in physics from Brown University.

Bethany Sparn led the construction of NREL’s Automated Home Energy Management laboratory (AHEM Lab) and is coordinating innovative demand response, HVAC, and hot water system research. She is an expert at data acquisition and control systems. Bethany received an MS in mechanical engineering from Colorado State University. She also holds a BS in mechanical engineering from Columbia University and a BS in physics and mathematics from University of Puget Sound.

† Corresponding author