Using Intelligent Efficiency to Collect and Analyze Nonenergy Benefits Information

Ethan A. Rogers and Eric Junga

November 2017

Report IE 1702

529 14th Street NW, Suite 600, Washington, DC 20045

Phone: (202) 507-4000 • Twitter: @ACEEEDC

Facebook.com/myACEEE • aceee.org

Contents

About the Authors

Ethan Rogers directs the day-to-day activities of ACEEE's Industry Program, coordinates the organization's work on intelligent efficiency, and is the program lead for the biennial Summer Study on Energy Efficiency in Industry. He leads ACEEE's analysis of energy use in the manufacturing sector and the effects of investments in efficient technologies and practices. The program also analyzes and reports on efficiency programs targeting the industrial sector, opportunities to increase the use of combined heat and power (CHP) to meet the nation's energy needs, and the ability of intelligent efficiency to transform all sectors of the economy. Ethan has a bachelor of science degree in chemistry and a master's degree in business administration.

Eric Junga conducts research for both the Industry Program and the Transportation Program at ACEEE. He contributes to research projects on intelligent efficiency, smart and connected devices, and energy use analysis in all industrial sectors. Eric performs analyses for ACEEE's annual GreenerCars environmental friendliness rating and is active in several light-duty vehicle research projects aiming to increase vehicle and transportation-related energy efficiency. Before joining ACEEE, Eric worked for a print-media manufacturer on large offset presses. He then earned a bachelor's degree in engineering physics and a master's degree in energy systems engineering, learning the intricacies of the energy markets and participating in Industrial Assessment Center energy audits.

Acknowledgments

This report was made possible through the generous support of Energy Trust of Oregon (ETO), Ontario Independent Electricity System Operator (IESO), New York State Energy Research and Development Authority (NYSERDA), and Pacific Gas and Electric Company (PG&E). The authors gratefully acknowledge external reviewers, internal reviewers, colleagues, and sponsors who supported this report. External expert reviewers included Mark Milby from Midwest Energy Efficiency Alliance, Richard Tonielli from Commonwealth Edison, Mary Chick and Chris Cochrane from NYSERDA, Rafael Friedman from PG&E, and Tim Guiterman from EnergySavvy. Internal reviewers included Neal Elliott, Jill Ferguson, Sara Hayes, Eric Junga, Maggie Molina, Steve Nadel, Reuven Sussman, and Shruti Vaidyanathan. External review and support do not imply affiliation or endorsement. Last, the authors thank Fred Grossberg for managing the editing process; Mary Rudy, Sean O'Brien, and Roxanna Usher for copyediting; Eric Schwass for graphics design; and Wendy Koch and Maxine Chikumbo for help launching this report.

Executive Summary

Information technologies and communication networks are enabling new ways of tracking and quantifying the many benefits of saving energy. Understanding the value of all these benefits changes the calculations used to justify investments. Rather than trying to justify an investment based on energy cost savings alone, we can add the value of other benefits into the equation to make a project more appealing.

The term *multiple energy benefits* (MEBs) encompasses energy savings and all other positive outcomes from an energy efficiency measure, project, or program. The more commonly used term *nonenergy benefits* (NEBs) refers to all the benefits that are additional to the energy saved.

Qualitative and quantitative MEB data have many uses. Program participants use this information to gauge the financial prudence of an investment. Policymakers can use it to assess the economic impacts of energy efficiency programs. Focusing on nonenergy benefits, this report deals with the collection and analysis of NEB data most likely to be of interest to professionals in the energy efficiency program space. These practitioners can use this information to improve their programs'

- Cost–benefit analysis related to individual investments and overall portfolio performance
- Marketing and customer relations
- Effects on the productivity and health of participants
- Environmental impacts

To understand automation's potential to collect and analyze NEBs, we focus on technologies that efficiency programs are likely to use and that are likely to have scale across one or more energy use sectors. We cover the collection and analysis of data in the residential, business, and public sectors, but not in transportation.

Current practices for determining NEBs include direct measurement, surveys, secondary sources, and modeling. Surveys are useful for collecting information on benefits such as comfort that cannot be measured directly. Collecting data for NEB analyses is often time consuming and expensive. Since programs have limited budgets to conduct surveys and perform analyses, their accuracy and precision are always a compromise.

To address these challenges, many program administrators are turning to information and communication technologies (ICTs) to improve NEB handling. Automating data collection and analysis reduces costs and speeds the delivery of actionable information to decision makers. Some new methods use conventional automation technologies, while others employ Cloud-based data analytics and machine learning. Some approaches access third-party databases and correlate that information with energy savings to identify relationships and trends.

Utilities can use their own data in NEB analysis. They can collect customer energy usage information from utility meters, local load data from distribution system control systems, and billing figures from customer information systems. Analysts can apply data analytics to merge information from utility systems and efficiency programs. They can then go on to identify correlations such as whether customers who participate in residential efficiency programs are less likely to be late paying their utility bills.

New methods for collecting insights into the benefits of energy savings often combine building or even room occupancy information with occupant feedback. In the short term, room conditions can be adjusted to meet people's preferences. In the long term, the application of machine learning will enable predictive adjustments that optimize energy use while also achieving other occupant goals.

Many customers have their own information management systems (e.g., a building automation system [BAS]) that can automatically collect information such as operating hours and building occupancy that is useful in NEB analysis. In the residential sector, smart thermostats, lighting, appliances, and other smart home products are all sources of information and points of control to enhance a home. Smart thermostats track the adjustments residents make and eventually predict and adjust the temperature to what occupants are likely to find comfortable. Many of these products add layers of convenience, for example by automatically turning on a light when someone arrives home at night. These additional conveniences may be more important to customers than energy savings, but that does not preclude their use in efficiency programs to achieve utility goals.

In commercial and institutional buildings, BASs are linked to HVAC, lighting, security, and other internal systems. Combining the details collected by their sensors with online data such as weather information and statistics from similar buildings can improve a BAS's performance. Several new companies have formed to help customers maximize building energy savings while also optimizing occupant comfort.

In manufacturing, process control systems collect production details that are useful in connecting energy savings and reductions in waste with improvements in productivity. Companies are installing low-cost sensors, leveraging wireless mesh networks, and using data analytics to collect and analyze process information. Energy management information systems enable firms to systematically track energy use and other costs and savings. New smart manufacturing software platforms collate these data streams and identify correlations.

Researchers are examining new automated methods for collecting feedback from building occupants and program participants. They are testing wearable technologies such as smart watches and biometric monitors to capture building occupant comfort and health information. Connecting wearable technology with building management systems could become a powerful tool to track NEBs and establish correlations with energy savings.

Data scientists are also mining public social media posts on platforms such as Facebook, Twitter, and Instagram. This modern form of sentiment analysis uses data analytics to identify and categorize attitudes toward particular topics, organizations, and products. Researchers and service providers are already harvesting Twitter data to determine the scope of a power outage. Program evaluators may be able to use these methods to assess the popularity or impacts of programs.

Many researchers and new solution developers are focusing on building occupant comfort. This does not always align with energy consumption, and the two are frequently in conflict. To be successful over the long term, the building automation industry and energy efficiency programs cannot pursue one without considering the other. Researchers are finding that a well-run building is often more efficient and that energy savings projects can improve occupant health.

Another important NEB category is operating costs. Controlling them is vital to organizations, so it is important to identify connections between saving energy and reducing other costs such as labor and materials. In offices, most costs are linked to labor, so researchers focus on the effects of energy savings on labor productivity. Workers' comfort and productivity can affect absenteeism, turnover, job satisfaction, health, and well-being.

In manufacturing, the focus is often on other operating costs. Co-benefits that are likely to be of interest include reduced scrap, product rejects, water use, downtime, wastewater, and safety risks. As each energy savings project is implemented, the production management system can make a date stamp to trigger energy data tracking and initiate a data mining analysis to identify and quantify coincident benefits. NEB analysis can be part of routine reports or even production dashboards.

The environmental benefits from efficiency may be direct, such as eliminating the generation of wastes onsite, or indirect, such as reducing pollution from power plants. Information from pollution-monitoring equipment can be correlated with energy usage information to identify patterns and document any reductions in emissions that develop post implementation. Software programs can convert energy savings values into reduced off-site emissions and automatically update an organization's sustainability reporting web page.

Automating the collection and analysis of NEB data has several implications for energy efficiency programs. It will help marketing departments deliver targeted messages that describe the full value of energy efficiency, enable customer service to help program participants quantify the benefits they are realizing, and allow public relations departments to share more detailed and timely information on the value provided by efficiency programs.

Likely the most important use of ICT in the collection of NEB data is in energy efficiency program evaluation, measurement, and verification (EM&V). Collecting and analyzing NEBs can be time and labor intensive. Results may not be available until months after a project or program has concluded, precluding the opportunity to make midstream corrections. Automation can reduce the cost of collecting data and improve the accuracy of analysis by using larger sample sizes.

Automated data collection will provide program evaluators with more routine and possibly more robust NEB data. This will be true for custom programs that need to quantify NEBs for a specific project and for prescriptive programs that use adders to deem the co-benefits of energy efficiency. Evaluators will be able to update adders more frequently and with sufficiently large data sets. They may even be able to develop NEB benchmarks for specific customer segments and end-use applications. Such information will give customers and policymakers more confidence in the value provided by efficiency programs.

The same data analytical tools that improve EM&V may also create new business opportunities. Utility customer service departments and the administrators of efficiency programs are well positioned to develop new services that monetize NEB information. They have the existing customer relationships, historical data for developing baselines, and the analytical tools required to identify trends and opportunities.

Barriers to the expanded analysis of NEB data range from technical to legal and ethical. The frequency of data collection, the definition of terms, and the units of measure must all be correlated if useful information is to be derived. Like the rest of the IT sector, the analysis of NEBs will not be immune to the data management challenges of privacy, ownership, and cybersecurity. Utilities and solution developers should adopt best practices for anonymizing data and then share only with trusted partners and researchers.

Where there is a strong case for the use of NEB data, for example to improve public health or the environment, but not a clear motivation for participation, policymakers may choose to create incentives to participate. Regulatory commissions could also aid innovation by providing guidance on proper use of NEB data. They could also create opportunities for utilities to work together and with other stakeholders to establish common definitions and protocols for data collection, transmission, distribution, processing, formatting, and contextualizing. This will facilitate the applicability of NEB analyses across territories.

New technologies and practices can lower the costs of data collection and bring to scale many energy savings measures. Improved analysis and dissemination of NEBs information can broaden support for energy efficiency programs. Improvements in impact analysis will increase the number of projects implemented, make programs more effective, decrease energy use nationally, and improve the economy and environment of the nation.

Introduction

Information technologies and communication networks are enabling new ways of tracking and quantifying the many benefits of saving energy. Investments in energy efficiency frequently are justified solely by cost savings. However this is seldom the only positive outcome of an efficiency measure. If we fail to include all the benefits of efficiency when we analyze projects and programs, we may bias the analysis by capturing all the costs but not all the benefits. Understanding the value of these benefits changes the calculations used to warrant them. Rather than trying to justify an investment based on energy cost savings alone, we can add the value of other benefits into the equation to make a project more appealing.

By quantifying the other benefits, program administrators, policy makers, and vendors can warrant allocating more resources to saving energy. Investors seeking to justify projects and customers interested in understanding the value they are receiving can use these data on multiple benefits. The information will also be of great interest to program developers, administrators, implementers, and evaluators, the utilities that fund them, and the public utility commissions (PUCs) that authorize them. Each of these stakeholders has a responsibility to ratepayers to invest funds wisely. Program developers and administrators must also assess the past performance of energy efficiency programs; evaluate current program design, purpose, and operation, justify future programmatic activity, and predict economic impacts. Having information on all the effects of their programs will facilitate these tasks.[1]

Not all program administrators are concerned with tracking and quantifying multiple energy benefits. This is often the case in states where PUCs and legislatures have a limited view of the value of energy efficiency. However many state PUCs across the country require inclusion of all the benefits in efficiency program cost–benefit analyses. This report addresses the issues faced by these stakeholders.

The American Council for an Energy-Efficient Economy (ACEEE) coined the term *intelligent efficiency* (IE) to describe energy efficiency enabled by responsive, adaptive, and predictive systems that use sensors, networks, data analytics, and machine learning. This suite of technologies improves our ability to collect and interpret data and thus to control devices and affect energy use. Learning thermostats are an example of intelligent efficiency. These Internet-connected devices can save energy with little intervention. Whereas a programmable thermostat depends on manually defined set points, a smart thermostat uses

[1] Multiple benefits are particularly important for cost–benefit analyses. The *National Standard Practice Manual for Assessing Cost-Effectiveness of Energy Efficiency Resources* (NSPM) is a best-practices resource for performing a cost–benefit analysis of an energy efficiency measure (Woolf et al. 2017). Baatz (2015) and Skumatz (2014) cover cost–benefit analysis in detail, so the topic is covered only briefly in this report.

sensors to assess the current condition of a home, machine learning to predict future demands by occupants, and data analytics to determine optimal operating conditions.[2]

Because the automated collection and analysis of nonenergy benefit (NEB) data are in their infancy, we have few examples and little history to draw from. However we can glean insights into what might be possible from the more frequent use of information and communication technology (ICT) to manage energy data. We may revisit the application of ICT to NEBs with an analysis of best practices once common methods have been established.

This report assesses the current use of technology to track, analyze, and quantify information related to NEBs and addresses potential applications. Our analysis begins with a definition of NEBs and then surveys current methods of collecting, analyzing, and using NEB data. We discuss the strengths and weaknesses of various approaches. Our analysis focuses on a select set of benefits that are important to stakeholders. We review several technologies that have the potential to automate the collection and analysis of data and explore how that can lead to the quantification of target benefits. We then address possible and likely limitations and conclude by suggesting actions stakeholders can take to maximize the potential of these promising innovations.

Scope and Methodology

Focusing on the use of NEB data within energy efficiency programs, this report deals with the technologies that are likely to have scale across one or more energy use sectors. We cover the collection and analysis of data in residential, business, and public sectors but not in transportation. Many of the NEBs covered in this analysis relate to residential, commercial, and institutional buildings; a few are specific to the industrial sector.

We gathered the information for this analysis through a literature review and interviews with professionals involved in analyzing NEBs, administering programs, and developing energy efficiency policies. This research identified several technologies that may provide information that will be useful in quantifying NEBs.

Nonenergy Benefits (NEBs)

The term *multiple energy benefits* (MEBs) encompasses energy savings and all other positive outcomes from an energy efficiency measure, project, or program. The more commonly used term *nonenergy benefits* (NEBs) refers to all the benefits that are additional to the energy saved. The terms *co-benefits*, *ancillary benefits*, and *nonenergy impacts* are synonymous with the term *NEBs* (Russell 2015).

NEBs fall into three categories: utility, participant, and societal (Malone 2014). Utilities are concerned with the need for generation, transmission, and distribution assets and the many

---

[2] Prior ACEEE research has covered the use of ICT to collect, quantify, and evaluate energy savings data (Rogerset al. 2015). This work expands the scope to include the many other benefits that result from energy efficiency.

costs of providing service. A utility NEB might reduce the need for assets or lower their cost. A participant NEB is any benefit realized by a utility customer in addition to energy cost savings. Societal benefits accrue to everyone (e.g., clean air and water). The following list is not exhaustive.

Participant benefits

- Improved indoor air quality (IAQ)
- Comfort, health, and safety
- Labor and time savings and increased productivity
- Reduced operating costs and extended equipment life
- Improved process control
- Increased amenity or convenience
- Water savings and wastewater reduction
- Increased asset value

Utility system benefits

- Avoided cost of generating energy and other operation expenses
- Improved customer relations
- Reduced arrearages and cost of collections
- Improved efficiency program effectiveness

Societal benefits

- Reduced pollution and environmental externalities
- Health-care cost savings
- Improved educational outcomes
- Reduced depletion of limited energy resources
- Economic competitiveness

It is important to note that the presence of a benefit in one group does not exclude it from another. For example, pollution reduction is likely to be important to participants, utilities, and society.

The cause-and-effect relationship of energy savings and other benefits is not always direct. This can complicate the motivations for energy projects and the valuing of benefits. Some NEBs are the direct result of energy savings. For others, the relationship is indirect. For example, energy-saving measures such as improved lighting, heating, and air-conditioning create more comfortable work environments, making workers and building spaces (e.g., offices and classrooms) more productive. Companies are less likely to move when their workers are more productive in a work space. When landlords see lower tenant turnover, they may be able to charge more for their properties. In commercial buildings, this will affect tenants' willingness to continue renting, and this in turn will increase the value of the property (Burr 2008; USGBC 2015; Newsham, Veitch, and Hu 2017).

We researched the use of technology to collect and analyze various NEBs and discovered that one of the most frequent application of ICT relates to increased comfort of building occupants. Quality of lighting, noise, indoor air quality, temperature, relative humidity

(RH), and potential hazards (e.g., slippery floors and hot surfaces) affect comfort. In addition to focusing on the recent use of ICT to track and quantify benefits related to comfort, our discussion also focuses on the following NEBs:

- Reduced operating costs (e.g., labor, materials, water, maintenance, quality control, and any variable cost of manufacturing a product or providing a service)
- Increased productivity of workers, processes, and building space
- Reduced environmental risks, adverse impacts, and costs
- Reduced health risks, adverse impacts, and costs

Uses of NEBs

Many benefits flow from energy efficiency, and the information related to those benefits can be put to many uses. Participants use this information to assess the financial prudence of an investment. Utilities and the programs funded by ratepayers have many uses for NEB data, some of which are dictated by public utility commissions (PUCs) (see Baatz [2015] and Kushler, Nowak, and Witte [2012]). Efficiency programs may use the data to educate customers about the financial and technical assistance they provide. Once a project is completed, both parties may collect information about co-benefits to evaluate the efficacy of an investment.

This report focuses on applications most likely to be of interest to efficiency program professionals, for example, utilities, utility regulators, and program developers, administrators, implementers, evaluators, and regulators. We find that NEB data can be used to improve the following.

Cost–benefit analysis. A comprehensive cost–benefit analysis quantifies and compares all the costs and benefits realized by participants, utilities, and society. PUCs require cost-effectiveness testing to determine whether the benefits of an energy efficiency program's investments of ratepayer funds outweigh the costs. Unfortunately, program administrators do not consistently include NEBs in these tests. They may also use NEB data to assess past program performance, justify future activity, and predict economic impacts (Kushler, Nowak, and Witte 2012; Baatz 2015; Skumatz 2014).

Marketing and customer relations. Quantitative information on the direct benefits to individuals will help programs build the case for an energy savings project and enable them to reach more people. Even more than saving energy, consumers may see particular value in nonenergy benefits such as home comfort, improved health, and convenient control of building systems (Cluett and Amann 2015; Skumatz 2014).

Individual and public health. People spend 90% of their time indoors, so the buildings where they work and live significantly impact their health. Insulation, air sealing, and heating, ventilation, and air-conditioning (HVAC) upgrades can mitigate health issues such as heat- and cold-related stress, allergies, asthma, and pulmonary and respiratory risks (Wilson 2017). Individual health benefits include fewer respiratory-related emergency room visits and reduced carbon monoxide poisoning (Wilson 2017; Cowell 2016). Energy efficiency provides public health benefits by decreasing the amount of pollution from factories and power plants.

Environment. Environmental issues include emissions and wastes that contribute to air, water, and ground pollution. The environment benefits when energy efficiency results in fewer wastes and emissions. Many organizations must routinely monitor and track their emissions and waste streams. They use this information for internal regulatory compliance and corporate sustainability needs. These data aggregated across a region are also useful for understanding changes in pollution released into air and watersheds.

Collecting and Analyzing NEBs: Current Practices

Before a cost–benefit analysis can start, analysts need quantitative information on the results and impacts of an energy efficiency measure. They can collect the needed data through direct measurement or surveys, obtain it from secondary sources, or develop it through models. Utilities can collect customer energy usage information from utility meters, local load data from their distribution system, and billing figures from their customer information system (CIS).

Some organizations already routinely measure the variables needed to determine NEBs. For example, environmental regulations require most manufacturing facilities to monitor all pollutants leaving the premises, so they have air emission data for key pollutants. Businesses regularly monitor inputs (labor, raw materials) and outputs (products, services, wastes) and determine various performance metrics.

Analysts can use secondary data sources and studies to estimate NEBs such as increases in property value, health benefits, and the ability of customers to pay their utility bills on time (Russell et al. 2015).

Many participant benefits cannot be measured directly and must be assessed through surveys. The goal is to establish a monetary value for benefits that have value to participants but are not easily quantified (e.g., comfort, reduction of noise, light quality, increased reliability, and fewer sick days) (Cluett and Amann 2015). Energy efficiency program evaluators use various survey methods to qualify and monetize participant benefits, including contingent valuation (willingness to pay), conjoint analysis (choice between two options), and relative valuation (value relative to energy costs) (Skumatz 2014; Amann 2006; Three3 and NMR Group 2016; Russell et al. 2015).

Evaluators may analyze primary data, secondary information, survey results, and research findings to develop a multiplier for calculating the value of nonenergy benefits. Often referred to as *adders*, these multipliers are a simple method for recognizing that efficiency projects and programs have impacts beyond energy savings.

Some utilities incorporate actual values of easily measured NEBs (e.g., water savings) into cost–benefit analyses. Some environmental impacts of energy consumption are readily calculated, for example the volume of scrap material and associated landfill tipping fees. A dollar value can be dictated by a regulatory body, selected from a published report or government agency finding, or determined through an organization’s corporate sustainability program.

Quantifying many other NEBs is usually not possible through direct measurement and requires more elaborate data collection and analysis. Since terms like *comfort* and *health* are nebulous, it is necessary to identify and use metrics that are indicative of general comfort and health. One such metric is the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) Indoor Environmental Quality (IEQ) indicator for acceptable indoor air quality (ASHRAE 2013a, 2013b).[3]

LIMITATIONS OF CURRENT PRACTICES

Primary data collection is often specific to a location and time, limiting its value. For example, coincident benefits in a plastic injection molding operation will likely not translate to a metal casting operation. Residential properties are more homogenous, so values collected and averaged from a large sample of homes are likely to have broad applicability. Some regional biases may still need to be considered; for example, the co-benefits realized in a northern climate dominated by winter heating will be different from those in a southern region dominated by air-conditioning.

Many secondary data sources also have limited applicability. Research projects are often narrow in scope and duration, so attributing their findings to populations beyond those studied requires caution. The transferability of NEB values varies depending on the homogeneity of participants, geography, climate, and specifics of a program (Skumatz 2016).

Survey methods present many challenges. Values can diverge widely across respondents, may not be properly bounded, and are subject to participant biases (Russell et al. 2015). Logistical challenges may exist as well. The questionnaires may not go to people who experience the benefits. In a company, the person responsible for implementing the product may not have responsibility for paying the utility bill or be aware of changes to energy consumption. The person paying the utility bills is probably not informed about the co-benefits such as reduced scrap rate or increased productivity. The person whose job got easier because of improved lighting is not likely to know the program that provided program incentives is seeking information on changes in productivity. Many surveys are conducted by phone or in person. In both methods, respondents may be difficult to reach and interviewers may be costly. In summary, surveys are time consuming, labor intensive, and usually expensive.

The precision of calculation limits the accuracy of adders. Analyses are labor intensive and the larger the survey sample size, the more expensive the analysis. Therefore, with few exceptions, adders are not specific to a customer but are applied as averages across a population. They tend to be conservative estimates, reflecting the level of uncertainty. Over the past 20 years, researchers have identified some NEBs, such as emission reductions and improvements in transmission and distribution (T&D) infrastructure reliability, that have low variation and are consistent across programs. Other benefits, such as comfort and

---

[3] Indoor environmental quality is a combination of thermal comfort, indoor air quality (IAQ), acoustic comfort, and visual comfort. Per ASHRAE standard 55-2013, IAQ can be determined using the percentage of time CO_2 concentration is less than 1,100 ppm.

equipment operation and maintenance (O&M), show little variation within energy measure and program types (Russell 2015; Skumatz 2014).

The societal impacts of efficiency programs vary depending on the type of program, region, and local industry mix. For example, a labor-intensive weatherization program will have a higher economic multiplier effect than an appliance replacement program. If the territory includes the region in which insulation materials are made, the job creation numbers will be even greater (Skumatz 2014). Although most efficiency programs do not consider such far-ranging impacts, they may be of interest to stakeholders concerned with the societal effects of energy efficiency.

The usefulness of NEB data between utility service territories is limited. Definitions for many types of benefits vary by state or even utility. Units of measure, frequency of data collection, and valuing of benefits are not consistent. These barriers limit evaluators' ability to analyze data, identify trends, and share findings with other program stakeholders.

Use of IE Technology to Save Energy

RESIDENTIAL

In the residential sector, smart thermostats, lighting, appliances, and other smart home products are sources of information and points of control to enhance a home. Many of these products add layers of convenience, for example by automatically turning on a light when someone arrives home at night. This convenience extends to comfort. For instance, Nest thermostats can use humidity information to control the home temperature in very muggy areas (e.g., Florida). This control can be especially valuable for properties that are not always occupied. When away, owners can set back the thermostat enough to save energy without creating the conditions for mold (M. Blasnick, senior building scientist, Nest Labs, pers. comm., July 2, 2017). Reduced risk of property damage, improved indoor air quality, and peace of mind are co-benefits of energy efficiency.

Emerging smart home hubs such as SmartThings, Wink, Alexa, Google Home, and many others interface with connected security, lighting, heating and air-conditioning systems, appliances, and many other devices in a home. These hubs offer limited benefits on their own, but they create a single point of control in a residence. For example, smart home hubs can provide information to lawn sprinkler control systems, lighting controls, and pet food dispensers (Nest 2017). By monitoring weather information, such systems can irrigate only as much as needed, saving both energy and water. These products can monitor, react, and act across devices in ways not previously possible. Many of these new applications will produce energy savings as a by-product of providing some other function.

Even without a hub, connected lighting and learning thermostats can function independently and offer a great deal of convenience. Ultimately, products like smart thermostats can be used to predict what settings will make residents comfortable while saving energy. Energy savings may be the co-benefit of other more desired conveniences and benefits offered by these devices.

COMMERCIAL AND INDUSTRIAL

A commercial building automation system (BAS) is frequently linked to HVAC, lighting, security, and other internal systems. Combining their sensor data with, for example, online weather information and historical performance of similar buildings can optimize occupant comfort.

With so many smart systems inside a building, the question of management arises. Multiagent control systems are possible and the subject of much research. Each smart system, or agent, will have a level of autonomy, be able to communicate with other devices, and determine how its own behaviors can help achieve the desired comfort target (Wang et al. 2012).

Google is using neural networks to optimize energy use in its data centers. Neural networks are computer algorithms that detect patterns and make decisions based on those patterns. By repeatedly crunching the data, the computer can develop a predictive model of behavior under various conditions. The Google system gathers information on electricity usage, water consumption, and outside air temperature so it can model the operation of its data centers. The model was refined until its predictions were almost completely accurate (99.6%). After proving the model was reliable, the company used it to identify problems and recommend ways to improve efficiency (Metz 2014). The benefit that drove this investment was energy cost savings, but the positive outcomes included water savings and improved control of facility HVAC systems (Rogers 2014).

With the CrowdComfort smartphone application, workers provide information to building operations staff through text and images. Photos of problems (e.g., flickering lights and inoperative vents) have a time and location stamp and go directly to the facility manager, who then forwards them to the maintenance person to do the work. Each person involved enters pertinent information (e.g., progress resolving a problem, preventive maintenance, or safety issues) on the same mobile device app (CrowdComfort 2017).

Sensors in building access systems (e.g., doors, turnstiles, and elevators) and carbon dioxide sensors (carbon dioxide is the by-product of people breathing) provide information on how many people are in a building and where they are located. A building automation system (BAS) can use this to optimize the internal environment and the energy needed to achieve desired set points (Cluett and Amann 2015; Papadopoulou 2012).

Overventilation can waste energy in conference rooms, meeting areas, and ballrooms that are frequently unoccupied. In these areas, facility managers may install demand-controlled options that use occupancy sensors for smaller spaces or carbon dioxide (CO_2) sensors for larger spaces to determine ventilation needs (King and Perry 2017).

Underventilation can result in poor indoor air quality. Without access to fresh air, the more people in a room, the greater the concentration of CO_2. Sensors can measure the CO_2 level, and the BAS can use the information to operate the ventilation systems.

Some researchers are experimenting with using Wi-Fi traffic as a proxy for how many people are in a room (Trivedi et al. 2017). The data help determine whether a room is occupied and how close to capacity it is. Such information can be used to turn lighting off and ventilation down when a room is empty and to increase ventilation and cooling when the space is full.

Manufacturing firms are installing low-cost sensors, leveraging wireless mesh networks, and using data analytics to collect and analyze process information. Most production management systems now contain computer dashboards that provide contextualized information that facilitates better decision making. Incorporating energy management information systems as stand-alone items or as features on existing production management enables companies to systematically identify energy savings opportunities and document associated cost savings (Rogers 2014).

Use of IE Technology to Track and Quantify NEBs

DATA

Big data is changing the way utilities and energy efficiency programs do business. Fehrenbacher (2012), Zhou, Fu, and Yang (2016), and others have identified several new sources of big data that are changing the energy sector:

- Customer data: utility smart meter energy use history
- Weather data: local historical and forecasted information
- Mobile data: aggregate information from employee and potentially customers' mobile devices
- Thermal imaging data: information to identify buildings with energy efficiency opportunities
- Clean energy data: information from customer-sited renewable energy systems
- Electric vehicle (EV) data: information from plugged-in EVs that function as nodes on the grid and send and receive data and power
- Transmission and distribution (T&D) line sensors: real-time T&D status
- Real estate data: detailed information on the properties served by a utility
- Geographical information system (GIS) data: spatial information of multiple characteristics of a region
- Dynamic pricing: time and locational value of energy and demand response
- Customer behavior analysis: data collected via behavior programs that attempt to nudge customers toward more efficient use of energy

Technology can improve existing data collection and analysis practices. The collection and distribution of primary data can be automated, which will reduce labor and the access time for actionable information. Some new methods use conventional automation technologies while others employ Cloud-based data analytics and machine learning. Third-party databases can be easily accessed, and that information correlated with energy savings to identify trends and relationships. A key advantage of Cloud computing is that it can be inexpensive and available to organizations everywhere.

The presence of smart technologies such as learning thermostats does not guarantee that needed data will be available. Automating the analysis and quantification of benefits will require a combination of new hardware, software, and data analysis practices. A smart electric utility meter is a key intelligent efficiency technology since it is part of a utility system network and allows for bidirectional exchange of information, but the data it provides must be correlated with other data sets to be helpful in the quantification of NEBs.

Commonwealth Edison, the electric utility for Chicago, launched an initiative called the Anonymous Data program. Third parties can access up to 24 months of 30-minute-interval energy use data sorted by ZIP code (ComEd 2017).

Ecobee, a manufacturer of smart thermostats, has recently begun making aggregated customer data available to researchers. Ecobee gives consumers the option of including their thermostat's interval information in an anonymized data set that the company is making available to researchers. Ecobee started with 750 customers in January of 2015 and were up to 7,500 in December 2016. Several universities (University of California, Davis, and University of Toronto), national labs (National Renewable Energy Laboratory and Lawrence Berkeley National Laboratory), and nonprofits (E4TheFuture, ACEEE, and Northeast Energy Efficiency Partnerships) have signed up. The data have been anonymized; only the thermostat number is identified. The information includes

- State and city
- Thermostat model
- Size of building (requires customer input)
- Number of occupants (customer input)
- Five-minute interval data on thermostat settings (Ecobee 2017)

Researchers can use this data set to answer questions like

- What percentage of customers have custom settings?
- What percentage of customers override their programming and how often?
- What are the most common set points?

By combining this information with other data sets, researchers may be able to determine how the energy uses of similar homes in different regions change from year to year. They can use such data sets to determine the average savings for many common energy efficiency measures and enter these values into technical reference manuals (TRMs). These values can be region specific and routinely updated. Since TRMs are widely used in the evaluation, measurement, and verification (EM&V) of many popular prescriptive rebate programs, routine updates will increase their scope of use and credibility.

Correlating disparate data streams is possible with new data analytic software packages. The companies that develop the software also offer data analysis (i.e., software as a service [SaaS]). Utilities can use these Cloud-based services to identify energy savings opportunities or track progress of a customer engagement program. As this market develops, SaaS tools will likely be able to reveal other opportunities (e.g., water savings or indoor air quality improvements) and track NEBs (e.g., participant comfort, reduced utility arrearages, and regional emission reductions).

BAS data can enable facility managers to anticipate and proactively respond to maintenance, comfort, and energy performance issues. The benefits will be lower equipment maintenance costs, higher occupant satisfaction, and reduced energy consumption and costs (King and Perry 2017). Much like a smartphone is a platform for apps, BASs are becoming platforms for many other services (e.g., tenant billing and relationship management systems). New companies (e.g., eSight, Lucid, Aquicore, and CircuitMeter) offer energy information management software products that provide dashboards to track building operating parameters, including energy usage. Many have options to automatically import tenant contract information and meter data so property owners can apply them in tenant billing (eSight 2017; Acquicore 2017).

Program evaluators can leverage the fact that many organizations are also interested in tracking multiple benefits. Businesses may already have systems for surveying their employees and customers on issues such as productivity and employee satisfaction. Some businesses incorporate surveys into existing quality programs through which employees routinely enter production and quality information into a computer or portable device. Filling out a survey on multiple energy benefits then becomes part of a standard operating procedure (SOP) that is also collecting other important information.

Many human resources departments have systems for collecting employee opinions and suggestions. When completing an online time card, workers might be polled on whether a recent workplace improvement project made a task easier, harder, or had no effect. Such a mechanism could also identify any positive or negative changes in employees' attitudes toward their work (Newsham, Veitch, and Hu 2017).

COMFORT

Our analysis identified comfort as a key NEB that will benefit from intelligent efficiency. Smart thermostats and advanced building automation systems can collect IAQ information from room sensors and serve as the platform for applications that query building occupants. Professionals in the energy efficiency program space have also indicated that occupant comfort matters to program participants because it is a key performance indicator (KPI) for other issues of importance. Newsome, Veitch, and Hu (2017) conclude that office workers are more productive when they are more comfortable. They also make the connection between comfort and individual health.

The challenge in tracking the comfort benefits of energy efficiency is developing simple and inexpensive methods for collecting and analyzing relevant information. The automated controls of each system can use the desired temperature, illumination level, and CO_2 concentration to determine needs. The software models use weather data to facilitate predictive control of HVAC and lighting systems. Although control models are based around comfort, not efficiency, minimizing energy use is a secondary goal and they can potentially achieve highest comfort with lowest consumption (Wang et al. 2012). To be successful over the long term, facility managers cannot pursue one without considering the other. Well-run buildings are not just more efficient, but also more comfortable and better for people's health.

In one research project, a control system included smart lighting fixtures that detected occupancy and illuminance levels and a smart thermostat that measured air temperature, relative humidity, air velocity, and carbon dioxide. The system used these inputs to manage the HVAC and lighting, thus improving visual and thermal comfort and overall energy use. Depending on the control strategy, they saved between 23% and 43% (Higuera et al. 2014).

Another study (Nagengast, Uddenberg, and Miller 2016) assessed the "comfort efficiency" of six portable classrooms in a school district in Hawaii by installing over 200 sensors to collect renewable electricity generation, thermal comfort, visual comfort, and air quality.[4] The Zero Net Energy (ZNE) classrooms achieved 40% lower energy use than their traditional counterparts. Using the Predicted Mean Vote methodology, researchers determined that the ZNE classrooms were more comfortable, too.[5] Thirty percent of the school districts in the United States have portable classrooms, so if allowances are made for differences in climate, the data and conclusions from this study have broader applicability than might at first be assumed.

Wang et al. (2012) also used a "comfort model" to assess the difference between the survey-measured value of discomfort and the conditions in the room. The model considers three comfort factors (temperature, illumination, CO_2). This model is particularly interesting because a BAS could use it to provide real-time feedback. An app could track how often thermostats and lighting dimmers are adjusted and link that information with data from sensors, eventually determining the optimal point for comfort and energy efficiency.

Researchers have developed an algorithm to control for joint demand response and thermal comfort. The objective of the algorithm was to integrate energy consumption with occupant behavior and guarantee thermal comfort while also taking advantage of utility demand response incentives to reduce energy costs (Korkas et al. 2016). The control system has data feeds for energy consumption and demand and a proxy for comfort. With the proper configuration, this same system could provide quantitative information on the correlation between savings and comfort.

The Comfy service provided by Building Robotics includes a smartphone app that workers can use to register whether they are too hot or cold. An online software service collates the information and provides results to managers on a customized dashboard (Comfy 2017). The constraints of the existing HVAC system are the limiting factor: the more control zones there are, the more responsive the service can be. Room temperature and ventilation can be adjusted to satisfy the preferences of the greatest number of workers, but not everyone will be content. Still, the service provides a feedback loop that is not available in conventional systems, and a UC Davis study found that the ability to respond, to have some level of control, often influences the perception of comfort (Sanguinetti et al. 2016). These types of closed loop exchanges will improve of occupants' ability to manage their environment and energy use and are likely to increase satisfaction with their workplace.

---

[4] In this analysis, comfort efficiency is the ratio of indoor environmental quality to energy use intensity. Indoor environmental quality is a combination of thermal comfort, indoor air quality (IAQ), acoustic comfort, and visual comfort. Per ASHRAE standard 55-2013, IAQ was determined using the percentage of time CO_2 concentration was less than 1,100 ppm.

[5] Six factors are used in the Predicted Mean Vote (PMV) thermal comfort model: indoor temperature, relative humidity, wind speed, mean radiant temperature, clothing value, and metabolic rate.

A lighting system can be equipped with sensors that measure the light provided through windows. The system can then adjust the luminaires to balance what is provided naturally. It can also minimize glare, a common side effect of poor lighting. If the system is linked to a BAS via a tenant comfort application, occupants can provide real-time feedback on the effectiveness of the lighting system (Rogers et al. 2013).

Wearable devices such as smart watches and biometric monitors may provide pathways to capture building occupant comfort and health. Connecting wearable technology with building management systems could be a powerful tool to track NEBs and establish correlations with energy savings. An early example of this technology is the Comfstat, a software infrastructure that discerns thermal comfort via individually worn sensors and relays that information to a smart thermostat (Barrios and Kleiminger 2017). Researchers have tested this technology on occupants who then provided feedback on comfort level. The wearable sensors measure metabolic rate (heart-rate sensor) from Android Wear smartwatches and Bluetooth chest straps and the watch's built-in heart-rate (HR) monitor. The study compared this information with temperature and humidity data and found that metabolic rate is closely linked to thermal comfort as it determines how much heat leaves the body. The study concluded that the methodology is highly accurate and that thermal comfort can be derived from heart rate and environmental data. The authors suggest that for greater accuracy, they could introduce a calibration tool to vote on the 7-point ASHRAE scale. They also suggested that better sensors will produce better results (Barrios and Kleiminger 2017).

The Barrios and Kleiminger research project indicates that wearable technologies like Fitbits and Apple Watches have the capacity to form feedback loops. After a comfort management system has responded to information from occupant wearables, it can query whether individuals are more comfortable and correlate that feedback with readings of heart rate and room temperature. Using machine learning, it can optimize comfort while minimizing energy consumption.

Data scientists have been mining public social media posts on platforms such as Facebook, Twitter, and Instagram. This modern form of sentiment analysis uses data analytics to identify and categorize attitudes toward topics, organizations, and products. Researchers and service providers are already harvesting Twitter data to determine the scope of a power outage (Bauman, Tuzhilin, and Zaczynski 2015), views of an organization and its products (Van Looy 2016), and public stance on hydraulic fracturing (IHS 2017). Sentiment analysis could be used to automate the analysis of utility customer opinions of programs and their benefits.

Other NEBs

Manufacturing Costs

The motivations for investments in automation and control in industry are largely connected to controlling costs. In some industries, energy costs are the driving factor. In others, labor or raw material costs are the impetus and energy cost savings is the co-benefit. Either way, collecting large quantities of time-series data on multiple aspects of a manufacturing process means the industry can determine and quantify associations between energy savings and other benefits (Rogers 2014).

Operating Costs

Reduced maintenance costs often correlate with energy efficiency because systems that operate optimally with respect to energy consumption also function properly. When equipment operates properly it lasts longer. It also may operate less often or at less than full capacity, extending the time between servicing and even life expectancy. If maintenance is done in-house, reduced costs include labor and materials. If contracted, the monthly service fee can be less. Demands on the maintenance staff also decrease when building occupants are more comfortable in their workspaces.

Automated tracking of this benefit will require establishing a preimplementation baseline of maintenance costs, recording when specific energy measures have been implemented, tracking postimplementation operating expenses, and then identifying any correlation between energy use and maintenance cost trends. As challenging as this sounds, it is possible with a building management system app that uses information from the energy management information system (EMIS), the preventive maintenance scheduling system, and the building manager's accounting system to perform the analysis.[6]

Once such a tracking system is in place, an existing BAS dashboard that shows correlating and diverging trends in energy and operations costs can provide routine reports. Identification implementation dates will allow users to assess the effect of a given energy measure on multiple operating costs.

Production Management

A manufacturing process that generates less waste is likely to use less energy. By definition, more efficient systems make greater use of inputs such as energy, raw materials, and labor. Is a more productive system making more efficient use of energy only or is it also using raw materials more efficiently?

In determining cause and effect, consider that all forms of inefficiency stem from misuse of energy: fuel, power, human labor. Manipulating nonenergy manufacturing inputs—raw materials, water, and air—requires energy. Using less to derive the desired product means the process is more efficient and productive. The first benefit therefore is saving energy, and other positive outcomes flow from its more efficient use.

Quantifying the benefits thus becomes the challenge for management. This may be easier in industry than in other sectors because modern production management systems already gather information at multiple steps in key processes throughout a facility. Future systems will collect and analyze data from all discrete steps in all processes in a supply chain. Intelligent efficiency, in the form of smart manufacturing software platforms that network all aspects of the enterprise, will provide information to people throughout the supply when they need it, and in ways that facilitate decision making. Collection, analysis, and distribution of NEB data will be part of this data management. Such information can be

[6] Total preventive maintenance (TPM) is a business practice of systematically focusing on proactive and preventive maintenance tasks to improve equipment reliability and productivity, tasks that can be scheduled and assigned through scheduling software.

analyzed to identify correlations and discern cause and effect. For example, optimizing a compressed air system will stabilize the pressure and flow of compressed air to all pneumatic devices in a plant (e.g., presses, actuators, and torque wrenches) so they work more consistently. Reduced scrap rates and increased throughput are likely outcomes. Smart manufacturing production management systems will identify and quantify these types of cost benefits.

Operating cost benefits likely to be quantified include reduced scrap, product rejects, water use, downtime, wastewater, and labor. As each energy savings project is implemented, the production management system can make a date stamp to trigger energy data tracking and start a data mining analysis to identify and quantify coincident benefits. Sharing information along the supply chain will lead to discoveries of new relationships and associated cost impacts, for example, the effect of a third-tier suppliers' more efficient metal casting process on the final product of an original equipment manufacturer (OEM). Tracking will reveal how such energy savings at one level of a supply chain affect the costs in others. The cause-and-effect information will give context for decision makers to fully understand the impacts of their choices.

Such automated analyses will also be useful for industrial efficiency program ex post project evaluations. Building NEB data collection and routine analysis into the project scopes will reduce the burden on evaluators and the inconvenience to program participants (Rogers et al. 2015). The Department of Energy (DOE) Smart Energy Analytics Campaign found that EMIS can help building operators communicate their needs and performance to their superiors, increasing the likelihood of project approval (NREL 2015).

Productivity in Office Buildings

King and Perry (2017, vii) found that "Tenants are increasingly demanding flexible, controllable workspaces, and some building owners are installing smart technologies to attract and retain tenants. In addition, improved indoor air quality and temperature control can lead to greater worker productivity." Building automation systems can be instrumental in tracking the relationship between energy efficiency and occupant productivity.

Defining productivity for an office environment can be challenging. What is considered important varies from person to person. The National Research Council (NRC) of Canada has examined this issue as part of its effort to determine whether green buildings have quantifiable benefits. The NRC identified several key performance indicators (KPIs) that can be used to assess the productivity of buildings (Newsham, Veitch, and Hu 2017; Newsham et al. 2017):

- Absenteeism
- Employee turnover
- Self-assessed performance
- Job satisfaction
- Health and well-being (symptoms)
- Health and well-being (overall)
- Complaints to facility manager

The first two KPIs are available from the human resources department. Routine surveys of employees can provide the second two. Health and well-being may be accessible through human resources records or may require some type of survey. Facility management may have both BAS historical records with supporting indoor air quality information and documentation of tenant complaints.

The NRC also identified the sources, or pathways for data to flow into a productivity analysis. Building automation systems are a key source of MEB data. Thompson et al. (2014) capture the organizing influence of building automation systems in figure 1.

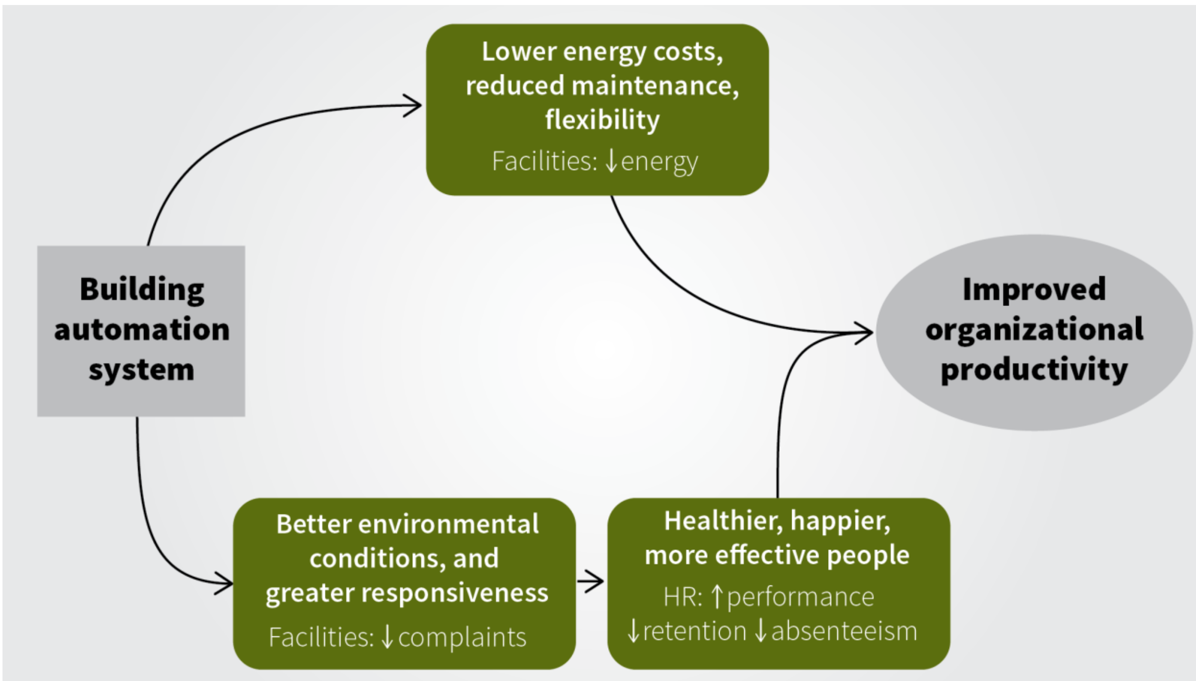

Figure 1. How building automation improves organizational productivity. *Source:* Adapted from Newsome, Veitch, and Hu 2014.

As building information management evolves, new software apps will be available to link these data streams. Anonymizing data from the human resources department will be necessary to protect privacy. Once that task is accomplished, aggregated data will enable trend analysis of the KPIs.

Although a single energy measure will not likely be the cause of building productivity, a correlation may exist between energy efficiency and a high-performing building. BASs enable simultaneous improvement in energy management and organizational productivity through the collection, analysis, and distribution of information.

Environment

Energy use and consumption of many chemicals contribute to local air and water quality. If a facility qualifies as a major source of air pollutants under the Clean Air Act, it must monitor some, but not all, on-site emissions. If combustion emissions are below a certain threshold (e.g., those from a gas stove) or are from mobile sources such as vehicles, reporting is not required. Nevertheless, an organization may, as part of a sustainability initiative, want to track energy-related emissions generated on-site.

Monitoring may include automated instrumental methods that continuously track emissions (EPA 2017). Correlating these data with energy usage information can identify patterns and document reductions in emissions following implementation of an energy savings project. Determining emission values requires only the volume of fuel consumed and the emission rate of the source. The latter can be derived from equipment literature or averages provided by government agencies such as the Department of Energy (DOE) and Environmental Protection Agency (EPA). Similar regulatory requirements apply to discharges into water systems and onto the ground.

Some energy savings projects have known environmental benefits, so documenting them means verifying implementation. For example, replacing a hydraulic plastic molding press with a nonhydraulic one means the new press will not produce any hydraulic oil waste. Environmental benefits of other projects may take time to manifest and require monitoring.

Automation requires connecting purchasing records with data analysis and dashboard programs. Something as simple as a smartphone app could collect, analyze, and report progress on reducing on-site emissions. A software app could automatically post data to the organization's website.

An organization may also want to track the emissions associated with generating the electricity they consume. Some building energy information management systems (e.g., CircuitMeter and eSight) can convert energy data of all fuel types into emission equivalents. Property managers can get reports that break down emissions by fuel site, building, and meter and distinguish between on-site emissions and those emitted offsite by the utilities supplying power (CircuitMeter 2017; eSightenergy 2017; Kistner 2017).

Health

E4TheFuture recently conducted a meta-analysis of 14 reports to assess the impact of residential energy efficiency programs on occupant and public health. The summarized studies used surveys, self-reports, and on-site air sampling to evaluate resident wellness (table 1). E4TheFuture tracked healthcare use (e.g., visits to hospitals) through surveys and healthcare claims. The analysis found that "it is not appropriate to value the health co-benefits of low income residential energy retrofits at $0 in program design or cost-effectiveness practices." In fact, the analysis found considerable value to individuals and to society (Colwell 2016, 8). According to Wilson (2017), many studies have found that people feel better, have fewer respiratory symptoms, and experience fewer headaches after implementing energy efficiency measures.

Table 1. Occupant health benefits of residential energy efficiency

Reduced respiratory and allergy symptoms	Overall health improvements	Reduced emergency department visits or hospitalizations	Indoor environmental conditions
Allergies	Headaches	Asthma	Moisture
*Asthma**	Hypertension	Other respiratory	Condensation
Colds	Thermal stress		VOCs
Sinusitis	Overall health		*Formaldehyde*
Throat irritation	Mental health		*Radon*

Italics: some negative outcomes. VOCs: Volatile organic compounds. *The majority of studies reported asthma improvements; however one study documented mixed results. *Source:* Cowell 2016.

Quantifying health benefits as a co-benefit of energy efficiency is challenging because studies are limited in scope and labor intensive to administer. Intelligent efficiency can help overcome this barrier.

Some studies referenced in the E4TheFuture analysis used air sampling equipment and data loggers to monitor allergens, volatile organic compounds (VOCs), formaldehyde, radon, moisture, and condensation. Although most BAS devices cannot track these air-quality variables, the price of sensor technology is rapidly falling. IAQ sensors and the devices to analyze them may soon be inexpensive and widely available.

Energy efficiency programs could work with healthcare initiatives to include such sensors and devices in building retrofit projects. IAQ and energy savings data could then be collected simultaneously and correlated with self-reporting well-being surveys.

Other

New connected and smart technologies allow us to analyze indirect benefits that have not previously been considered. For example, it would have been too cumbersome to develop correlations between the types of businesses in a building, their potential for energy savings, and the likelihood they will renew their lease (the co-benefit). However quantifying a co-benefit such as tenant retention might be possible with data analytics and large data sets.

Individual building systems will collect information and share with an organization's network. For example, lighting fixtures can be embedded with sensors to assess room occupancy and even the movement of people and assets (e.g., vehicles or production subassemblies). Such systems will save energy and improve safety and security. In retail stores, such occupant-sensing lighting can aid user interactions and wayfinding.

NEB analysis can also help property managers increase the productivity of a building. A 2016 survey by Johnson Controls queried more than 1,200 facility management executives on key drivers for investing in energy efficiency in their buildings. Two-thirds indicated that increasing their company brand reputation and attracting new tenants were substantial investment drivers (Johnson Controls 2016). A study by Jones Lang LaSalle found that a 2% improvement in employee productivity equates to saving $6 per square foot in operating costs (JLL 2014). Automating the collection of these types of data using BASs and sentiment analysis will help property managers communicate the value of their green buildings and more readily realize a return on their investments through increased property valuation, higher lease rates, and lower tenant turnover.

Sentiment analysis is also providing new ways of assessing the performance of an organization and its products and services. ESRI, a software developer and solution provider, used ArcGIS, a geospatial software platform, to provide Seattle City Light with geolocated social media comments on power outages in its service territory (Esri 2017). The Social Media Sentiment Viewer SaaS developed by another geographic information system (GIS) company, ArcGIS Solutions, overlays a map of a utility's service territory with public opinions related to that utility's infrastructure. It harvests information from Twitter, Flickr, and YouTube. Companies like Esri and ArcGIS Solutions market these services to utilities for use in emergency and nonemergency events to assess the public's view of the utility or its infrastructure. ArcGIS Solutions also markets the Damage Assessment Collector, through which customers can send photos of damaged power lines and transformers from a mobile device. Real-time photo evidence about the nature and scope of the damage allows utilities to prepare and execute a more efficient response (ArcGIS 2017).

Program administrators could use sentiment analysis to delve into the public perception of program offerings. They might also be able use it to geolocate areas of heightened interest in energy efficiency and likely program participation.

Implications for Energy Efficiency Programs

Energy efficiency programs use MEB information in their marketing efforts to increase participation in programs, improve customer service engagements, evaluate the performance of individual programs and overall portfolios, and improve program design. Automated collection and analysis of benefit information will improve those functions and lead to new business opportunities.

Sensors and data collection devices will become cheap enough to be deployed and forgotten—left in buildings to collect data on air temperature, humidity, lighting levels, carbon monoxide, carbon dioxide, and various air contaminants. The data they collect will be streamed to the Cloud and available for analysis of trends and correlations. To capitalize on this opportunity, program implementers may want to deploy all types of sensors when a project starts. They can gain acceptance by treating the deployment as an engagement function. In exchange for allowing the installation of nonintrusive sensors, customers will be enrolled in an efficiency program and eligible for incentives. They will also get access to the same data for managing their own operations.

PROGRAM EM&V

Likely the most important use of ICT for collecting benefits data is in efficiency program evaluation, measurement, and verification (EM&V). As previously discussed, collecting and analyzing NEBs can be time and labor intensive. Results may not be available until months after a project or program has concluded. Automation can reduce the cost of data collection by requiring less labor, improve accuracy by using larger sample sizes, and accelerate the reporting of results.

Quantifying the reduction in other operating costs (e.g., maintenance, raw materials, water, and wastewater) may also be important to program evaluation. The ability to quickly collect, analyze, and report such information will help programs document the value they bring to customers.

Program evaluators will benefit from more robust data. This will be true for custom programs that need to quantify NEBs for a specific project and for prescriptive programs that use adders to deem the co-benefits of energy efficiency. As technology enables the collection of more data, evaluators will be able to update adders more frequently. With sufficiently large data sets, they may even be able to develop NEB benchmarks for many customer segments and end-use applications.

Marketing and Customer Service

Efficiency programs frequently use NEB information when engaging customers. For example, a weatherization program may tout increased comfort and health in promotional materials. Automating the collection of individual health information and documenting improvements in building occupant comfort will provide data to support and improve the details of marketing materials.

Comfort is a component of satisfaction that has an impact on tenant retention and lease rates (Newsham, Veitch, and Hu 2017; Newsham et. al 2017). As Jones Lang LaSalle reported, increased productivity can also translate into increased lease rates (JLL 2014). Administrators of commercial building retrofit programs have told us that improving tenant retention and lease rates are motivators for program participation.

Customer service interactions, many of which are conducted online, can also use MEB information. For example, many efficiency programs have online portals where customers can assess the energy status of their homes or businesses. As customers learn about savings, they can also learn about other benefits of participation in a program. The more specific and quantitative the list of additional benefits, the more useful it will be.

Using NEB information to communicate value to customers gives program implementers an advantage over the conventional practice of presenting a few case studies. Customers know that details specific to an individual project are not always relevant to their project. Gathering and analyzing large amounts of data can provide a clearer estimate based on unique attributes. Telling a customer "according to our analysis of 1,000 similar projects, you can expect 10–15% energy savings and 5–10% productivity improvement" is likely to be more believable.

As customers are engaged and projects implemented, more detailed information is gathered. Utility smart meter data, especially in the residential sector, often track energy savings remotely. Postimplementation outreach to customers can direct them to the web portal where they can register other benefits of energy savings measures. With larger commercial and industrial projects, personnel can enter on-site data from direct measurements and participant surveys through mobile devices connected to project-tracking databases.

The final step is to correlate customer billing and energy data with specific program implementation information and customer feedback to automate discovery and quantification of participant benefits. This information can feed back to marketing and customer service so they can update their customer engagement materials. Such linkages will also establish correlations between program participation and other customer interactions (e.g., reductions in customer delinquencies and arrearages). These uses of NEB data will attract more customers, increase economic impacts, and improve cost effectiveness.

NEW BUSINESS OPPORTUNITIES

The ability to use a wide variety of data to identify and quantify MEBs creates new business opportunities for utilities and entrepreneurs. Many customers will have little interest in conducting their own analyses because the subject is complicated and requires specialized knowledge and software. Customers will seek trusted partners to help them understand and process the torrent of information. Utilities can promote and support markets and private investment in this space. They can also develop their own services to help customers monetize NEB data. Doing so will grow existing customer relationships and create new ones. Utilities have multiple databases and can, for example, use their own emission tracking information to help customers with their emission reporting. Utilities can also leverage third-party services to add new capabilities such as improving the productivity and space utilization of buildings and the comfort and health of occupants (Navigant Research 2017).

A customer's NEB data are valuable not only to them directly but also to others as part of an aggregated data set. Programs have the infrastructure to capitalize on this opportunity. A utility might want to work with research organizations on a data set such as the previously mentioned Ecobee data-sharing initiative. Such a collaboration could discover a new business case that could then be tested in a pilot project.

Customer energy management systems such as smart thermostats and BASs may provide a work-around for those lacking smart meters and the interval data they provide. Heating and air-conditioning run-time data can help approximate real-time energy use and behavior information that can be used in energy savings analysis. Customers may not have the expertise to analyze all the data their devices provide. Programs can build such analysis into their service package.

Deployment Challenges

We have covered several technical methods for collecting and analyzing data, but not all the methods we have listed are developed or will be deployed. Barriers to deploying these practices range from technical to legal and ethical.

Technology

A typical large utility collected about 24 million meter readings per year before the introduction of advanced metering infrastructure (AMI).[7] With AMI, that number will increase to about 220 million meter readings per day (Zhou, Fu, and Yang 2016). Managing these data (i.e., collecting, transmitting, processing, distributing to stakeholders, providing in a contextual visual format, and then acting upon them) will be a challenge. Utilities must also cyber protect such information, adding another layer of complexity and cost. To maximize the value of energy and NEB data, their timeliness, integrity, accuracy, and consistency must improve. These steps require organizational information technology (IT) resources and staff time (Zhou, Fu, and Yang 2016).

The devices that control things cannot be the only source of data collection. Such devices always have first-order priorities that limit their usefulness in collecting and reporting NEB data. In addition, programs will need to deploy sensors just to collect and monitor continuously if they are to scale the analysis of NEBs across a customer segment. Such deployment will be limited by the cost of sensors and installation.

Many utilities will need to upgrade their IT infrastructure. Organizations must develop policies and procedures related to data collection, control, and governance. Data definition, storage, and management need to be standardized across organizations and industries (Rogers et al. 2015).

The abundance of variables in complex operational processes, each at different levels of granularity and spatial and temporal detail, can confound data processing and analysis. Making sense of a jumble of data streams will require professionals trained in management of big data and intelligent efficiency to integrate modeling elements and parameter settings at multiple scales. The energy field is migrating away from the domain of the mechanical engineer to require data scientists, IT professionals, energy management specialists, and social scientists (Zhuo et al. 2016). Given the need for specialized resources, the cost of these new types of analyses may also prove to be a barrier.

The Green Button program is an example of how government involvement and industry leadership can address data issues. The White House issued a call to action to provide electricity customers with easy access to their energy usage data in a consumer- and computer-friendly format via their electric utility's website. The industry responded and now 60 million customers can access their information online (Green Button Alliance 2016).

Data Security and Privacy

Organizations that collect and analyze large volumes of customer data have a responsibility to protect that information from unauthorized exploitation. Companies will be directly liable and could suffer financially from the negative publicity should their data be compromised. Such leaks have cost many retailers millions of dollars in lawsuits and

---

[7] Utility smart meters are the best-known example of AMI, an integrated, bidirectional communication network associated with a utility distribution grid.

expenses related to corrective action. A recent report by IBM Security estimated that data breaches of US-based energy and utility companies caused damages of $7.4 million per incident (Ponemon Institute 2017).

Collecting MEB data is additionally challenging because it combines data streams from systems that historically have been isolated. Each new connection between systems is a potential access point for those who would create mischief. One program manager mentioned that concerns about data security limited commercial property owners' participation in their monitoring-based commissioning (MBCx) programs. The programs required remote access to data from the BAS in exchange for financial assistance to optimize the operations of the HVAC and control systems. Some building operators worried that others could exploit the link.

In addition to stealing and exploiting customer data, the potential for compromising building systems and denying service or access is a concern. A smart building where the management and security connect could lock tenants out of their own offices, as happened in a hotel in Austria (Johnson Controls and Booz Allen Hamilton 2017).

Another barrier is the possibility of bad publicity and a negative public image. Some people worry that utilities could use smart meters to monitor their activities and share the information with other entities that would exploit it. Others find the capability intrusive. Concerns about privacy and control of personal data are key societal issue. Between smart meters, smartphones, and wearables, most of a person's daily activities can be observed, tracked, recorded, and shared. We do not address this issue in detail in this work but recognize that peoples' privacy concerns will continue to be a challenge for efficiency programs and efforts to quantify and monetize MEBs.

We do not have a simple fix. Cyber issues are part of the operational landscape of business operation in the 21st Century just as protecting against fire has been for centuries. The solution is to develop a cybersecurity strategy that identifies risks and integrates cyber capabilities across the organization. Securing a smart building involves risk-based planning, security architecture, technology, best practices for data management, and skills and knowledge at all levels of the organization. Cybersecurity is a day-to-day operational issue we must address through a continuous improvement effort (Johnson Controls and Booz Allen Hamilton 2017; Zhou, Fu, and Yang 2016).

Sharing customer data is often a challenge for utilities because of privacy issues and state regulatory requirements. The issue of who owns the information can determine how it may be used. For example, a utility that has access to customer AMI data but not to details collected by the thermostat (e.g., heating and cooling set points) might offer rebates to participants in an efficiency or demand-response program in exchange for thermostat information. Using parallel data streams from the meter and the thermostat could result in more robust qualifying and quantifying of NEBs.

Consumer advocates often posit that the data belong to the customers and should not be shared unless they have agreed to the sharing and the utilities have presented clear use case and described how the information will be used. The data being considered in the public policy discussions are largely energy related, but other streams might be available in the future. Therefore the issue of NEB data ownership and management and how it relates to various public policy goals is worth considering now.

Is it better for customers to have to opt into or out of sharing their utility data? The former gives customers more control; the latter creates more opportunities for solution developers, who often point out that sometimes you do not know what is possible until you have the raw material in hand—in this case, raw data. The challenge then becomes how to secure the data after developing the new use case.

One option for providing usage information is to remove identifiable customer details and provide data for large populations only. Another possible solution is to first determine how to protect the information and then build those features into the software. In such a scenario, the data are summarized at the network edge or device level. The device could determine the co-benefit and report that value rather than the source data. An example is the recent ENERGY STAR® connected thermostat measurement and verification (M&V) methodology. Service providers have an EPA-accepted algorithm that captures the energy use of multiple homes in a utility service territory and aggregates the data before sharing a summary of a region's energy savings with the utility and the EPA.

MARKET

Lack of a strong use case frequently hinders the advance of new technology. Just because someone builds it does not mean customers will come. The Green Button is a great technology, but very few people use it (Rogers and Junga 2017). In a world where many individuals and organizations spend more money on telephones than on electricity, how much time and effort can they justify focusing on energy?

For example, people might agree to linking building management systems with wearable technologies if there is a strong value proposition. Individuals routinely allow the navigation apps on their phones to keep track of their location because it is part of a service they value. However they may not see the same advantage in providing metabolic information to an energy management system just to save a few dollars on their electric bill. Gaining customer interest may require additional benefits.

Professionals in the utility sector indicate that willingness to focus on energy and concerns of privacy fall along customer sectors. A significant fraction of residential customers have expressed concerns about utilities using their meter data to learn personal details and sharing that information with others. By contrast, few business customers seem to have the same anxieties. They are more likely to view an energy efficiency program as just another vendor using consumption data to increase the value of its services. Given this dynamic, businesses may be the more approachable candidates; the residential market may require an opt-in approach such as is developing with smart thermostats and home energy management hubs.

As mentioned, utility customer service departments and the administrators of efficiency programs are well positioned to develop a new market for services that monetize NEB information for customers. Being proactive is important. A vendor that is the broker of customer data and its analysis is more likely to own the customer relationship. If this is a concern for a utility, it can offer data analysis services using its own CIS and AMI systems to collect NEB information.

Utilities seeking to offer new analytical services can start by automating surveys and on-site data collection. Next, they can source more data streams from connected devices. Where internal capabilities are insufficient, they can work with third parties to identify new use cases and develop data management practices that present the least risk for theft and misuse. This will often require working with vendors' aggregated rather than source data; however this should be acceptable for many applications. Utilities can incrementally provide their customers with a portfolio of energy data analysis services.

Policy Considerations

Policymakers can facilitate the automation and use of NEB data by taking a holistic approach to the benefits of efficiency that accrue to participants, utilities, and society. No single government entity serves all these groups, so policies must encourage agencies and other stakeholders to work together and share resources.

Enabling Broader Use of NEB Information

Public utility commissions may want to consider which additional services they want utilities to provide in the public interest and then initiate discussions on how they should be provided and to what end. Using NEB information to help customers understand the value of efficiency is one possibility. PUCs might also want programs to have specific NEB goals in addition to energy savings goals. Energy efficiency has always been a form of economic development. Tracking NEBs will inform policy discussions on the full impact of programs.

Utilities can help expand the use of NEBs in new services and territories. To drive adoption of smart technologies, they can cultivate demand for NEB data by directing program implementers to collect and share it with participants. As customers become accustomed to using NEB data in their operations, they will request their own analysis services, fueling the development of companies along the supply chain.

Multiple research projects have demonstrated the connection between energy and other end-user operating cost savings and the linkage with productivity and worker satisfaction. Intelligent efficiency technologies may make providing such services a viable business venture.

Working with community health organizations is another opportunity. Analyses conducted by E4TheFuture and others show that energy efficiency contributes to individual health by creating a safer, healthier environment. Programs are quickly becoming proficient at analyzing large quantities of data and discerning correlations. Allowing programs to collect health impact information will improve the justification for weatherization programs and could lead to new public health initiatives.

A third chance to increase the societal impacts of efficiency programs is to connect them with economic development and community development initiatives. Sharing NEB information with such initiatives will demonstrate to them and their constituencies the full value of energy efficiency. Understanding the benefits could encourage economic development agencies to target resources such as grants and tax abatements on helping new and existing companies invest in energy efficiency so they can become more productive, grow, and hire more employees.

Policymakers can help expand the use of NEB information in general by supporting program marketers' use of such data. Customers are more likely to participate if they have a complete understanding of the benefits. In some states, this may require a review of how customer motivations affect the determination of free ridership. Vendors in the private sector are not constrained as to how they use NEB information to sell an energy savings product or service. However many efficiency programs are prohibited from discussing NEBs to avoid encouraging free ridership. This of course limits their ability to attract participants. In the interests of achieving a desired public good, agencies or contracted third parties should also be able to use all the information they have to motivate program participation.

COMMON DEFINITIONS AND PROTOCOLS

Automation enables scale but only if all the connected devices can communicate with each other. Definitions of individual NEBs and their use in cost–benefit analyses are not uniform across the country. This limits data sharing between jurisdictions. As regulators consider this topic, they could aid innovation by providing guidance on proper use of NEB data. They could also create opportunities for utilities to work together with other stakeholders to establish common definitions and protocols for data collection, transmission, distribution, processing, formatting, and contextualizing. Common inputs are the first step to creating data that can be aggregated and shared between programs. PUCs can encourage utilities and programs to participate in initiatives such as Haystack that are working on such tasks (Haystack 2017).[8] This will facilitate the applicability of NEB analyses across territories. This will also reduce the need for each utility to learn and develop everything alone. It will ultimately enable a larger, more robust market that uses NEB data as raw material in providing many value-added services.

PRIVACY AND SECURITY

Like the rest of the utility sector, the analysis of NEBs will not be immune to the policy challenges of data privacy and ownership and the technical challenges of cybersecurity. The privacy and ownership issues of NEBs are no different from those regarding customer energy data. Therefore commissions may find it useful to expand their policies regarding customer energy data to also cover associated NEB information.

Customers are likely to resist having programs collect and share NEB information unless they are comfortable with how it will be handled. Regulators should encourage or require programs to develop cybersecurity strategies that include adopting data management best practices, identifying risks and communicating them to customers, educating customers on

[8] Project Haystack is a collaborative effort of efficiency program software developers to streamline working with data from the Internet of Things (IoT). IoT applications include automation, control, energy, HVAC, lighting, and other environmental systems.

their responsibilities for proper data management, and integrating cyber capabilities across the supply chain.

Conclusion: Next Steps

Saving energy is one of many benefits that motivate customer action. Sometimes it will be the primary motivation; other times it will be a co-benefit of another driver. Optimizing the use of energy requires embracing both.

The automation of data collection and analysis is just beginning. All stakeholders should recognize that energy efficiency is changing because more data are more readily available. Interest in quantifying NEBs is likely to grow as new practices reveal new information. In the next few years, we expect to see the collection and analysis of more sources of data and increased use of coincident benefit information that is likely of greater quality and quantity. Cumbersome practices will give way to more automated and insightful analysis methods.

NEB information will increasingly be used to assess the impacts of energy efficiency on other operating costs. Automated data collection from sensors and participant surveys will improve the efficacy of program measurement of NEBs. It will also expand the number of benefits that can be monitored and analyzed for correlation with energy savings. Program participants and administrators will ultimately have a greater understanding of the value of individual projects.

The analysis of comfort appears to be the most promising near-term use of NEB data. Several companies offer software services that leverage existing building automation and Cloud computing to provide facility managers with near real-time feedback from occupants. Comfort information has great value because it is a KPI of employee and tenant satisfaction and worker productivity. The use of NEBs to assess comfort is likely to grow in the near term, and use of comfort as a KPI in efficiency program evaluation seems likely.

A promising but not imminent use of automated NEB data collection is assessing individual health changes that result from energy efficiency. By monitoring indoor air quality and data from wearable devices and correlating them with building energy use patterns, we can assess the health impacts of weatherization and other efficiency programs. Such automated systems may not be available for several years. In the short term, we expect to see more research to test data collection and analysis methodologies.

Greater support for energy efficiency policies is possible with targeted sharing of NEB information. Economic development and environmental initiatives may be more likely to support energy programs when presented with quantitative information correlating energy efficiency with improvements in productivity, worker retention, worker health, and generation of wastes.

Policymakers can create opportunities for efficiency programs to collaborate with public health, economic development, and community development initiatives to expand the benefits of the programs. Sharing benefit information across a collaboration will allow each member to demonstrate to its respective stakeholders the full value of its actions.

New technologies and practices can lower costs of data collection and bring scale to many energy savings measures by simplifying their justification. Improved analysis and dissemination of NEB information could broaden support for efficiency programs. These improvements in impact analysis will increase the number of projects implemented, make programs more effective, decrease energy use nationally, and improve the economy and environment of the nation.

References

Amann, J. 2006. *Valuation of Non-Energy Benefits to Determine Cost-Effectiveness of Whole-House Retrofits Programs: A Literature Review.* Washington, DC: ACEEE. aceee.org/research-report/a061.

Aquicore. 2017. "Automate Your Utility Bill-Back Process." Accessed November. aquicore.com/tenant-billing/.

ArcGIS. 2017. "Social Media Sentiment Viewer." Accessed September. www.arcgis.com/home/item.html?id=fbcb90bd26ca4fd888470ab1ba6d817a.

ASHRAE (American Society of Heating, Refrigeration and Air Conditioning Engineers). 2013a. *ASHRAE Standard 55-2013: Thermal Environmental Conditions for Human Occupancy.* Atlanta: ASHRAE. www.ashrae.org/.

———. 2013b. *ASHRAE Technical FAQ ID #35*. Atlanta: ASHRAE. www.ashrae.org/.

Baatz, B. 2015. *Everyone Benefits: Practices and Recommendations for Utility System Benefits of Energy Efficiency.* Washington, DC: ACEEE. aceee.org/research-report/u1505.

Barrios, L., and W. Kleiminger. 2017. "The Comfstat—Automatically Sensing Thermal Comfort for Smart Thermostats." In *Proceedings of the IEEE International Conference on Pervasive Computing and Communications*. New York: IEEE (Institute of Electrical and Electronics Engineers). www.vs.inf.ethz.ch/publ/papers/LilianaBarriosPaper.pdf.

Bauman, K., A. Tuzhilin, and R. Zacynski. 2015. *Using Social Sensors for Detecting Power Outages in the Electrical Utility Industry*. New York: Stern School of Business, New York University. people.stern.nyu.edu/kbauman/research/papers/2015_KBauman_WITS.pdf.

Burr, A. 2008. "CoStar Study Finds Energy Star, LEED Bldgs. Outperform Peers." *CoStar News*, October 26. www.costar.com/News/Article/CoStar-Study-Finds-Energy-Star-LEED-Bldgs-Outperform-Peers/99818.

CircuitMeter. 2017. "Generate Greenhouse Gas Reduction Analyses Automatically." Accessed September. www.circuitmeter.com/solutions/energy-monitoring-systems/

Cluett, R., and J. Amann. 2015. *Multiple Benefits of Multifamily Energy Efficiency for Cost-Effectiveness Screening*. Washington, DC: ACEEE. aceee.org/research-report/a1502.

ComEd. 2017. "Anonymous Data Service." Accessed October. www.comed.com/SmartEnergy/InnovationTechnology/Pages/AnonymousDataService.aspx.

Comfy. 2017. "Comfy." Accessed July. www.comfyapp.com/.

Cowell, S. 2016. *Occupant Health Benefits of Residential Energy Efficiency*. Framingham, MA: E4TheFuture. e4thefuture.org/wp-content/uploads/2016/11/Occupant-Health-Benefits-Residential-EE.pdf.

CrowdComfort. 2017. "CrowdComfort." Accessed August. crowdcomfort.com.

Ecobee. 2017. *Donate Your Data: Researcher Handbook.* Toronto: Ecobee. www.ecobee.com/wp-content/uploads/2017/01/DYD_Researcher-handbook_R7.pdf.

EPA (Environmental Protection Agency). 2017. "Title V Operating Permits." Accessed September. www.epa.gov/title-v-operating-permits/epa-issued-operating-permits.

eSightenergy. 2017. "Carbon and Sustainability Reporting." www.esightenergy.com/esight-platform-2/carbon-sustainability-reporting/www.esightenergy.com/esight-platform-2/carbon-sustainability-reporting/.

Esri. 2017. "Electric Utilities." Accessed October. www.esri.com/en-us/industries/electric-gas-utilities/segments/electric.

Fehrenbacher, K. 2012. "10 Ways Big Data Is Remaking Energy." *GigaOm*, January 29. gigaom.com/2012/01/29/10-ways-big-data-is-remaking-energy/.

Green Button Alliance. 2017. "Green Button Alliance." www.greenbuttonalliance.org/about.

Haystack. 2017. "Project Haystack." Accessed November. project-haystack.org/.

Higuera, J., W. Hertog, M.J. Perálvarez, and J. Carreras. 2014. "Hybrid Smart Lighting and Climate Control System for Buildings." In *Proceedings of the IET Conference on Future Intelligent Cities*. London: IET (Institution of Engineering and Technology). www.researchgate.net/publication/269332624_Hybrid_smart_lighting_and_climate_control_system_for_buildings.

IHS Markit. 2014. *Energy Sentiment Pulse*. London: IHS Markit. www.ihs.com/pdf/Energy-Sentiment-Pulse-Brochure-6849-0914TB_174413110913044932.pdf.

JLL (Jones Lang LaSalle IP, Inc.). 2014. *Green + Productive Workplace™*. Chicago: JLL. www.us.jll.com/united-states/en-us/Documents/green%20productive%20workplace%20overview_JLL_april2014.pdf.

Johnson Controls. 2016. *2016 Energy Efficiency Indicator (EEI) Survey: Global Summary.* Milwaukee: Johnson Controls. *www.johnsoncontrols.com/-/media/jci/insights/2016/be/files/be_2016_eei_global_summary.pdf?la=en*.

Johnson Controls and Booz Allen Hamilton. 2017. *Cybersmart Buildings: Securing Your Investments in Connectivity and Automation*. Milwaukee: Johnson Controls; McLean, VA: Booz Allen Hamilton. www.johnsoncontrols.com/-/media/jci/be/united-states/specialty-pages/files/be_wp_cybersmartbuildings.pdf.

King, J., and C. Perry. 2017. *Smart Buildings: Using Smart Technology to Save Energy in Existing Buildings.* Washington, DC: ACEEE. aceee.org/research-report/a1701.

Kistner, J. 2017. "Carbon Accounting Capabilities for Green Compliance." *CircuitMeter*, April 12. www.circuitmeter.com/industry-articles/carbon-accounting-capabilities-green-compliance/.

Korkas, C., S. Baldi, I. Michailidis, and E. Kosmatopoulos. 2016. "Occupancy-Based Demand Response and Thermal Comfort Optimization in Microgrids with Renewable Energy Sources and Energy Storage." *Applied Energy* 163 (February 1): 93–104. www.sciencedirect.com/science/article/pii/S0306261915013823.

Kushler, M., S. Nowak, and P. Witte. 2012. *A National Survey of State Policies and Practices for the Evaluation of Ratepayer Funded Energy Efficiency Programs*. Washington, DC: ACEEE. aceee.org/research-report/u122.

Malone, E. 2014. "Driving Efficiency with Non-Energy Benefits." Presentation to the 2014 National Symposium on Market Transformation. Washington, DC: ACEEE; Boston: CEE (Consortium for Energy Efficiency). aceee.org/conferences/2014/mt-program.

Metz, C. 2014. "Google Uses Artificial Brains to Teach Its Data Centers How to Behave." *Wired*, May 28. www.wired.com/2014/05/google-data-center-ai.

Nagengast, A., S. Uddenberg, and M. Miller. 2016. "ZNE vs. Comfort: A Holistic Look at High Performance." In *Proceedings of the 2016 ACEEE Summer Study on Energy Efficiency in Buildings* 10: 1–10. Washington, DC: ACEEE. aceee.org/files/proceedings/2016/data/papers/10_651.pdf.

Navigant Research. 2017. *Intelligent Building Technologies for Value-Added Services*. Chicago: Navigant Research. www.navigantresearch.com/research/intelligent-building-technologies-for-value-added-services.

Nest. 2017. "Works with Nest." nest.com/works-with-nest.

Newsham, G., J. Veitch, and V. Hu. 2017. *Effects of Green Building Certification on Organizational Productivity Metrics*. Ottawa: National Research Council Canada. nparc.cisti-icist.nrc-cnrc.gc.ca/eng/view/fulltext/?id=9cae7920-03d1-459e-ab14-2fef54016a92.

Newsham, G., J. Veitch, M. Zhang, A. Galasiu, I. Henderson, and A. Thompson. 2017. *Improving Organizational Productivity with Building Automation Systems.* Ottawa: CABA (Continental Automated Buildings Association). www.caba.org/documents/reports/CABA-IOPBAS-2017-Report.pdf.

NREL (National Renewable Energy Laboratory). 2015. *Realizing High Performance Buildings.* Golden, CO: NREL. www.nrel.gov/docs/fy15osti/62530.pdf.

Papadopoulou, E. 2012. *Energy Management in Buildings Using Photovoltaics*. Basel: Springer International Publishing AG.

Ponemon Institute. 2017. *2017 Cost of Data Breach Study*. Armonk, NY: IBM Security.

Rogers, E. 2014. *The Energy Savings Potential of Smart Manufacturing*. Washington, DC: ACEEE. aceee.org/research-report/ie1403.

Rogers, E., R. Elliott, S. Kwatra, D. Trombley, and V. Nadadur. 2013. *Intelligent Efficiency: Opportunities, Barriers, and Solutions*. Washington, DC: ACEEE. aceee.org/research-report/e13j.

Rogers, E., E. Carley, S. Deo, and F. Grossberg. 2015. *How Information and Communications Technologies Will Change the Evaluation, Measurement, and Verification of Energy Efficiency Programs*. Washington, DC: ACEEE. aceee.org/research-report/ie1503.

Rogers, E., and E. Junga. 2017. *Intelligent Efficiency Technology and Market Assessment.* Washington, DC: ACEEE. aceee.org/research-report/ie1701.

Russell, C. 2015. *Multiple Benefits of Business-Sector Energy Efficiency: A Survey of Existing and Potential Measures*. Washington, DC: ACEEE. aceee.org/research-report/ie1501.

Russell, C., B. Baatz, R. Cluett, and J. Amann. 2015. *Recognizing the Value of Energy Efficiency's Multiple Benefits*. Washington, DC: ACEEE. aceee.org/research-report/ie1502.

Sanguinetti, A., M. Pritoni, K. Salmon, and J. Morejohn. 2016. "TherMOOstat: Occupant Feedback to Improve Comfort and Efficiency on a University Campus." In *Proceedings of the 2016 ACEEE Summer Study on Energy Efficiency in Buildings* 8: 1–12. Washington, DC: ACEEE. aceee.org/files/proceedings/2016/data/papers/8_442.pdf.

Skumatz, L. 2014. *Non-Energy Benefits/Non-Energy Impacts (NEBs/NEIs) and Their Role & Values in Cost-Effectiveness Tests: State of Maryland; Final Report*. New York: NRDC (Natural Resources Defense Council). energyefficiencyforall.org/sites/default/files/2014_ NEBs report for Maryland.pdf.

——. 2016. "Non-Energy Benefits/NEBs—Winning at Cost-Effectiveness Dominos: State Progress and TRMs." In *Proceedings of the 2016 ACEEE Summer Study on Energy Efficiency in Buildings* 6: 1–13. Washington, DC: ACEEE. aceee.org/files/proceedings/2016/data/papers/6_1147.pdf.

Three³ and NMR (Three³, Inc. and NMR Group, Inc.). 2016. *Massachusetts Special and Cross-Cutting Research Area: Low-Income Single-Family Health- and Safety-Related Non-Energy Impacts (NEIs) Study*. Boston: Massachusetts Program Administrators. ma-eeac.org/wordpress/wp-content/uploads/Low-Income-Single-Family-Health-and-Safety-Related-NonEnergy-Impacts-Study.pdf.

Trivedi, A., J. Gummeson, D. Irwin, D. Ganesan, and P. Shenoy. 2017. "iSchedule: Campus-Scale HVAC Scheduling via Mobile Wi-Fi Monitoring." In *Proceedings of the Eighth*

International Conference on Future Energy Systems 132–42. www.ecs.umass.edu/~irwin/ischedule.pdf.

USGBC (US Green Building Council). 2015. "The Business Case for Green Building." February 10. www.usgbc.org/articles/business-case-green-building.

Van Looy, A. 2016. "Sentiment Analysis and Opinion Mining (Business Intelligence 1)." In *Social Media Management*, 133–47. Basel: Springer International Publishing AG. link.springer.com/chapter/10.1007/978-3-319-21990-5_7.

Wang, Z., Wang, L., A. Dounis, and R. Yang. 2012. "Multi-Agent Control System with Information Fusion Based Comfort Model for Smart Buildings." *Applied Energy* 99 (November): 247–54.

Wilson, J. 2017. "Health Benefits of Residential Energy Efficiency." Presentation to the 2017 ACEEE/CEE National Symposium on Market Transformation. Washington, DC: ACEEE; Boston: CEE. aceee.org/sites/default/files/pdf/conferences/mt/2017/Wilson_SessionC1_MT17_4.3.17.pdf.

Woolf, T., C. Neme, M. Kushler, S. Schiller, and T. Eckman. 2017. *National Standard Practice Manual for Assessing Cost-Effectiveness of Energy Efficiency Resources*. National Efficiency Screening Project. nationalefficiencyscreening.org/wp-content/uploads/2017/05/NSPM_May-2017_final.pdf.

Zhou, K., C. Fu, and S. Yang. 2016. "Big Data Driven Smart Energy Management: From Big Data to Big Insights." *Renewable and Sustainable Energy Review* 56 (April): 215–25.