Commercial Building R&D Program Multi-Year Planning: Opportunities and Challenges

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ABSTRACT

Commercial buildings use 18% of the United States' energy and 35% of its electricity, and have commensurate impacts on environmental emissions. The Energy Information Administration's (EIA) Reference Case projects that this sector's energy use will grow 1.7%/year through 2025 – a growth rate exceeded only by the transportation sector. Therefore, buildings represent a substantial opportunity for realizing national benefits through energy efficiency, if research and development (R&D) can deliver significant and timely performance and cost breakthroughs.

Formulating an effective R&D portfolio requires effective planning, especially when the approach to energy efficiency moves from the evolutionary to the revolutionary. The central purpose of this paper is threefold: 1) to describe the Department of Energy's (DOE) commercial buildings R&D scope and the planning context; 2) to summarize some of the fundamental challenges to planning in commercial buildings R&D; and most importantly, 3) to provide an overview of the strategic framework for R&D decision-making that DOE is developing to realize the promise of net zero energy performance in the 2020 to 2025 time frame.

The paper describes progress to date, and remaining work to be done, in developing a persuasive framework for making defensible and transparent decisions about R&D for both new and existing commercial buildings.

Introduction

This paper has four main sections. The first provides a brief overview of commercial buildings energy use trends in the U.S. and defines the national importance of this sector. The second section briefly discusses DOE's overarching net zero energy goal for buildings and defines the context for performance-based R&D planning, including the importance of linking R&D outputs to energy savings outcomes in actual buildings. The third section highlights three of the challenges to R&D planning in commercial buildings: the diversity of commercial buildings; the lack of fundamental data; and the significant gap between design intent and performance in high-performance buildings. The heart of this paper, the final section, provides a "progress report" on DOE's recent commercial buildings planning activities. Detail is provided on the strategic planning framework under development at DOE, a framework designed to address the challenges to R&D planning. This section also discusses a number of actions DOE is taking now to realize the ultimate promise of net zero energy buildings.

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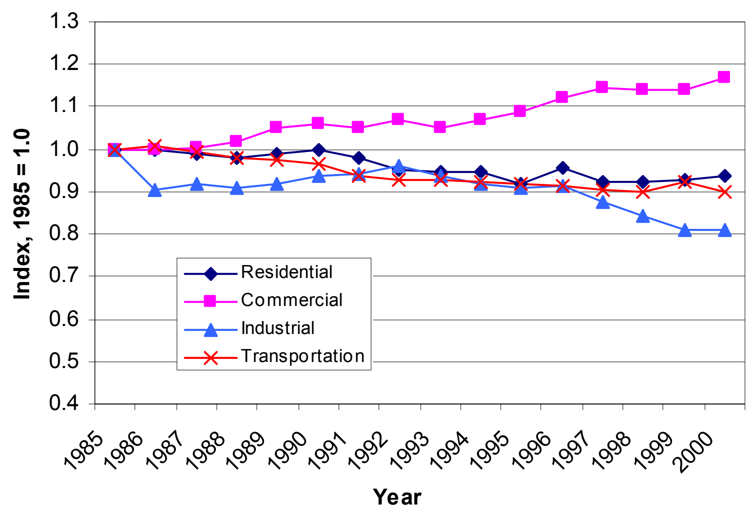
U.S. Commercial Buildings Energy Context

Commercial buildings are a significant and growing consumer of America's energy resources. America's 4.7 million commercial buildings span a great variety of functions, sizes, operating schedules and types, from large "24/7" hospitals to small retail stores. Providing the necessary energy services in these buildings (lighting, comfort, fresh air, cooking, and power for computers and other equipment) required 17.4 quadrillion Btu (quads) in 2002, 18% of the Nation's annual energy use (DOE 2004a). Commercial buildings also constitute the most electric-intensive sector in the country; 76% of their energy services are provided by electricity, and they consume 35% of the Nation's total electricity.

Despite some significant improvements in energy performance in this sector – such as T8 lamps with electronic ballasts, improvements in chiller efficiencies, Federal standards for HVAC equipment – the historical trend for commercial buildings is *increasing* primary energy intensity (Btu/ft^2/year) (Figure 1). From 1985 to 2000, the energy intensity of the commercial sector increased by 17%, while all other sectors have decreased: residential, down 6%; transportation, down 10%; and industrial, down 19%.

Figure 1. Total Primary Energy Intensity by End-Use Sector, 1985-2000



Source: DOE 2003a

Looking to the future, "reference case" projections of energy use by the Energy Information Administration to 2025 indicate that the second fastest-growing energy sector of the economy, after transportation, will be commercial buildings, with an annual growth rate of 1.7% per year, compared to residential at 1.0% per year growth rate. The impact of this growth is a need for another 8.5 quads of primary energy (DOE 2004a).

DOE Program and Planning Context

The DOE's Building Technologies Program (BT) goal for both the residential and commercial sectors is aggressive: to develop cost-effective technologies, techniques and tools for buildings such that they can produce as much energy as they use on an annual basis, in the 2020 to 2025 time frame. The aim of BT research is to reduce total energy use per building by 60 to 70% (DOE 2004b). Such reductions potentially allow renewable sources to serve the remaining loads and deliver zero (net) energy buildings, measured over the course of 1 year.

The resources dedicated to realizing this aggressive vision are modest. For FY 2005, BT's total budget request to Congress is $58 million and of this, about $7 million is specifically focused on commercial "whole building" R&D (DOE 2004b).

Whole-Building Definition

A whole-building focus means the design, construction and operation of the commercial building as an integrated system to maximize energy performance. Careful daylighting design, for example, involves attention to building orientation, façade design, window area, window performance, interior design, and the control of electric lighting systems to maximize the use of natural light. A systems approach carefully integrates these factors to optimize building energy performance. Commercial whole-building R&D encompasses a wide portfolio of opportunities such as:

- tools for building design and simulated energy performance
- improved design and decisions processes
- sensors and controls for HVAC, lighting and distributed power systems
- understanding the interaction of ventilation, indoor environmental quality and health impacts
- hardware and software systems to diagnose and correct performance deficiencies.

Planning Context

The President's Management Agenda (PMA) requires all Federal agencies to develop clear "performance measures" as part of the program planning process. Measures should be:

- specific (precisely stating what will be accomplished)
- quantifiable (the level of achievement is relative to a defined baseline)
- achievable (the goal is achievable with the resources)
- auditable (factual information that can be examined by the Office of Management and Budget and the General Accounting Office).

These measures must clearly delineate the causality between R&D outputs, and actual energy savings outcomes in real commercial buildings.

Experience with DOE peer review committees such as the National Research Council has shown that the link between research outputs and outcomes in the market can be difficult to establish for systems integration areas, such as improved building simulation design tools (NRC 2001). The difficulty is twofold. First, the savings impact *per unit* must be established and documented relative to a clearly defined baseline. This is much harder than for hardware technologies such as windows. For a simulation tool, what *is* the baseline? A different simulation tool? Heuristic rules of thumb? While case studies of individual buildings can provide insight into the per unit impact, the results cannot usually be generalized to the national population of buildings. Second, the actual usage (or market penetration) of the tool or new practice in the overall market must also be ascertained and documented. Because such design and usage data are not collected by EIA or the Census Bureau in their national survey instruments, there is very little basis for selecting the baseline, much less monitoring the rate of penetration of new practices. Things that can be measured (such as software downloads and attendance at training sessions) are very indirect, and largely inadequate, measures of actual energy savings.

Challenges to R&D Planning

A number of challenges face long-range, whole-buildings R&D planning for commercial buildings. Three significant ones are:

- extreme diversity in the characteristics and energy use patterns of buildings
- the lack of national-scale, statistically significant buildings data
- the uncertainty of realizing savings in actual high performance buildings caused by gaps between design intent and actual as-built performance.

A Diverse Sector

Designing a whole-buildings R&D portfolio for commercial buildings begins by clearly answering the question, which commercial buildings market segment should be targeted to achieve the greatest impact in achieving per building energy use reductions of 50 to 70%? Buildings are diverse across a large number of dimensions, but here we will consider only three – building size, function and vintage. In each case, different target segments imply a different focus when developing an R&D agenda.

Considering the stock of buildings by building size indicates that distinctly different market segments exist. Buildings less than 5,000 ft^2 in floor area constitute one-half of the Nation's buildings, but only 10% of total square footage and 13% of the electricity use. Buildings greater than 100,000 ft^2 constitute 2% of the buildings, but 47% of the square footage and 54% of the electricity use. Put simply, most of the energy is used in a small number of large buildings. Large and small buildings differ in terms of HVAC system type, opportunities for daylighting, and surface-to-volume ratios. The opportunities for systems integration R&D differ accordingly.

Building function is another "diversity" indicator. EIA uses 20 different building types to characterize the sector. Building type matters, because commercial buildings exist to provide services, and services determine the overall intensity and kind of energy use (see Table 1). The design and technological challenges inherent in designing and operating a warehouse with 50 to 70% reductions in energy use are different from those of a hospital. Those differences include operational profiles, size, and end-use demands.

Table 1. Building Energy Use by Function

	Average Size ('000 ft^2)	% of total site energy used by all commercial buildings	Energy Intensity ($kBtu/ft^2/yr$)	Largest End-Use
Hospital	75	9	295	H_20 heating
Office	14.9	19	97	Lighting
Warehouse (non refrigerated)	14.5	6	37	Heating
Education	25	12	79	Heating

Source: DOE 1998

Whether the R&D target is new construction or existing buildings also matters. For existing building stock, basic design decisions have largely been made (i.e., orientation, shape, glazing area and construction materials). Realizing very aggressive improvements in existing buildings (those in excess of 50%) usually requires great effort because the degrees of freedom are limited. "New" buildings (those yet to be built) offer a much richer set of opportunities for greatly improving whole-building performance. This market is 2.5 to 3.0 billion ft^2 per year through 2025 (DOE 2004a).

Lack of Data

BT's R&D focus is national in scope. For robust R&D planning, the most useful data are publicly available, statistically significant, and national in coverage. Case studies from states or cities may provide critical insight, but usually are not amenable to extrapolation to the nation as a whole because of differences in energy prices, fuel availabilities, utility rebates and other factors.

The Commercial Buildings Energy Consumption Survey (CBECS), conducted quadrennially by the EIA provides basic statistical information about energy consumption and characteristics of buildings, and is an invaluable source. Nothing else, on the national scale, is even close in terms of characterizing the stock. Nevertheless, CBECS does not provide much of the detailed information needed to inform R&D planning.

CBECS is a survey of respondents, and is now conducted using computer-assisted telephone interviewing. It does not include even a cursory on-site survey of the building. In this sense, it is a survey of the impressions of the respondents rather than a description of the actual building, let alone of operation and maintenance (O&M) practice. As a consequence, CBECS does not provide information about important areas, such as:

- building orientation and geometry
- the nameplate capacity, performance and vintage of the HVAC system
- specific information about the energy management control system (if any)
- how the HVAC control system is actually used in practice
- whether the building has an active operations and maintenance program
- window characteristics, including thermal and solar heat gain performance.

For new construction, there are other distinct data gaps. These include a lack of statistically significant information on "current practice," the degree of compliance with building energy codes; the extent to which energy performance simulation tools are used in building design; and the degree to which such designs are actually implemented in real buildings.

For existing buildings, a particular challenge is establishing what the cost-effective energy savings potential is of conscientious O&M practice. Most case studies put the range between 5% and 30% (Hunt and Sullivan 2002). However, the sample sizes are low and the rigor of the evaluations of variable quality. Understanding what the O&M potential is, nationally, and understanding how whole-building R&D breakthroughs might help capture this potential remain serious data deficiencies.

Gap between Design Intent and Actual Performance

Even at the building component level, actual performance in real buildings may differ from predicted performance because of differences in installation, operation and other factors. This can lead to much lower energy savings than an optimal analysis would predict. Systems-integration approaches, because they are considerably more complex than component approaches, present greater challenges. More complexity increases the probability for errors in design and execution, and thereby for greater divergence between design intent and actual building performance.

Analysis conducted for BT by the National Renewable Energy Laboratory (NREL) provides important insight into the potential extent of the gap between intent and performance. NREL monitored the actual performance of five high-performance buildings and evaluated the results, which indicate that the challenges to exemplary performance are formidable, even when the owners and designers are committed to it. These five case buildings ranged from 12,000 to 41,000 ft^2 in floor area and were one or two floors; they included a National Park visitor center in Utah, an educational facility in Ohio and an office building in Maryland (Griffith, Deru and Torcellini 2004; Pless and Torcellini 2004; Torcellini et al. 2004). All included daylighting as an integral design feature. Photovoltaic (PV) systems ranged from 4 to 60 kW of rated capacity. Relative to a code-compliant building, site energy savings ranged from 25% to 62%; of the remaining load, solar's contribution ranged from 1 to about 60%.

The case studies document some of the problems encountered in realizing high levels of performance in buildings through systems integration in design and operation, rather than simply combining a number of exemplary components. Some lessons learned include:

- All aspects of daylighting design must be carefully integrated to realize electricity savings in lighting. Several buildings designed to harvest sunlight had non-reflective interior surfaces, did not include daylighting sensors, and had no measured daylighting savings.
- A holistic approach to the design, installation and control of PV systems is needed - as opposed to aggregating components – to maximize solar's contribution. Three buildings had problems with PV system performance because of inverter faults, less-than-optimal PV placement, inefficient transformers and lack of controls.
- Optimizing performance after construction may take considerable effort. In one case, the building's performance from the first to third year improved from 30% savings to nearly

50% based on recommendations provided by NREL. This illustrates the magnitude of the "shortfall" between design intent and actual performance.

In summary, even in the best case – in new construction, with owners committed to high performance - realizing exemplary whole-building performance is very challenging. The BT role and approach to this challenge will now be described.

Past and Future Planning Approaches

Historically, the mission and scope of BT's Commercial Buildings Program has spanned the entire range of commercial building performance, from buildings that are minimally compliant with building energy codes to the kind of high performance buildings described above. While the focus has been on new buildings, the Program has also dealt with existing buildings. The Program has attempted to cover this extremely broad range of opportunities without a clearly defined strategic framework for decision- making. Consequently, the Program has had less focus than desirable, especially given its historically modest funding level relative to the energy savings potential of this sector. Given the planning context described earlier, and the requirements for quantifiable and specific metrics of performance, such an intuitive approach is no longer appropriate.

Today, our approach to planning is governed by the overall BT goal of achieving the technical and economic potential for zero net energy buildings (ZEB) by 2025. Our planning efforts are thus focused on two immediate objectives:

- defining and evaluating programmatic pathways to achieve ZEB
- balancing and integrating ZEB-focused efforts with other opportunities.

To meet these objectives, BT is developing a strategic framework for decisions that is responsive to the President's Management Agenda described earlier and produces performance measures that are quantifiable, specific and achievable. The strategic framework provides a means for linking various programmatic initiatives (projects, technologies, etc.) with overall program goals through objective performance metrics (energy savings, market penetration, etc.) over time.

The diversity of the commercial buildings sector and the lack of data described earlier indicate that a reasonably complete, high quality decision framework will take considerable time to develop. Therefore, the framework will be constructed in stages. In the meantime, DOE will make decisions on 2005 and 2006 projects using best available data and knowledge.

The essential part of developing a new strategic framework is to identify economically achievable ZEB-focused objectives over time. DOE will establish objectives through two types of analyses: *Opportunity Assessments*, which characterize and rank the technical and market opportunities for reducing energy use; and *Program Evaluations*, which evaluate a range of prospective program initiatives to capture the savings. In an ongoing program, Opportunity Assessments and Program Evaluations are more or less continuous planning activities, conducted at various levels of detail as needs dictate and refreshed periodically as new data becomes available. For the Commercial Program, the new focus on ZEB mandated that DOE initiate several new, broad-based Opportunity Assessments and supporting activities in FY 2004. These analyses have been designed and scheduled so their results will feed into the annual revision of the formal BT multi-year plan, which supports budget decisions.

BT has historically performed data collection and analysis of opportunities to support planning for many of its programs. Two examples are illustrative. An extensive technical and market analysis and a program evaluation were an essential step in developing a new BT market transformation program in response to Sections 127 and 128 of the Energy Policy Act of 1992 (DOE 1995). Over the past 10 years, BT has also conducted a series of studies which characterize the energy consumption characteristics and potential impact of emerging and advanced technologies within a segment of the market, such as HVAC (Roth, Goldstein and Kleinman 2002). Most of the past studies focused primarily on traditional energy use sectors (HVAC, lighting and appliances) and were mainly of use in developing component-based strategies. As discussed below, beginning in FY 2004, DOE began several studies on commercial whole-building technologies and practices.

The Path Forward for New Construction

The initial major Opportunity Assessment will focus on new construction, because of the ZEB focus of the program. The objectives of this Opportunity Assessment are as follows:

- Test the ZEB technical hypothesis via simulations analysis: how low can you go with current, emerging and advanced technologies?
- What levels of performance do advanced technologies have to meet to achieve ZEBs on a widespread basis?
- Identify achievable whole-building performance levels considering various technical, economic and institutional constraints.
- Identify key technologies and practices to achieve high performance building (HPB) performance levels.
- Identify market sectors presenting the greatest opportunities.

One of the outcomes of the Opportunity Assessment will be to define a hierarchy of building performance that might be achievable in the marketplace in stages over a 20-plus year planning horizon, and might look like that shown in Table 2.

Initially, the Opportunity Assessment will focus on a one or two building sizes and types that appear most likely to achieve ZEB levels and most significant in terms of aggregate energy consumption. This pilot study will be completed in 2004. It will establish the analytical approach for the overall study and identify the cost and performance data requirements. Moreover, the results of the pilot study will provide quantitative performance metrics for the specific building market segment studied.

Subsequent analyses will systematically search across the entire commercial sector for additional target markets.

Table 2. Hierarchy of Building Performance Levels

Performance Level		Energy Use
High Performance Buildings (HPB):		
	Net Zero Energy Buildings (ZEB)	100% less
	Ultra-Low Energy Buildings (ULEB)	75% less
	Low Energy Buildings (LEB)	50% less
Better Practice (Energy Star)		20 – 30% less
Conventional Good Practice (Code Compliant)		Baseline

Advanced building component and equipment technologies (windows, HVAC, lighting, on-site renewable power, etc.) will be a major contributor to achieving HPB performance. A significant outcome of the Opportunity Assessment will be to define the component and equipment cost and performance needed to achieve various whole- building performance levels. In particular, the assessment will focus on whole-building integrated technologies and practices. These technologies and practices include effective design guidance, improved energy analysis tools, advanced whole-building controls, daylighting strategies, and effective integration of on-site power technologies such as PV. For both components and integrated systems approaches, the Opportunity Assessment will focus on defining least-cost optimized pathways to achieve various performance levels. Some expected issues in conducting an Opportunity Assessment include the following:

- Theoretical versus actual performance of components, equipment and systems
- Lack of cost and performance data for key components, systems and practices
- Impact of building controls on load management, utility interfacing, operations
- Changing nature of technology, driven by increasing use of intelligent technology
- Difficulty in assessing whole-building integrated technologies and practices.

Whole-building technologies and practices (controls, design methods, etc.) are difficult to assess because their impact is inherently interactive and more highly influenced by the way they are applied. In addition, supporting data on the current market penetration of whole-building technologies and per-building energy savings are very limited.

The Path Forward for Existing Buildings

In the future, DOE will conduct an overall Opportunity Assessment for existing buildings. This sector is very important because existing buildings will dominate national energy consumption over the next 20 years. The scope of this assessment will include opportunities in commissioning and diagnostics, improved O&M practices and retrofitting. The results will identify technologies and practices that apply to both existing and new buildings, thus increasing their impact. The results of this assessment will provide a basis for balancing the program between the longer-term ZEB focus and the near-term opportunities in existing buildings.

To support the Opportunity Assessment, DOE is currently conducting a comprehensive meta-study of the energy savings potential for commissioning, based on experiences with real buildings. Another DOE study is examining the potential for control systems to enhance building operations and minimize the gap between design intent and actual performance. Both studies will be completed in 2004. Preliminary results indicate that the gap in performance in

HVAC, lighting and refrigeration systems amounts to between 0.4 and 1.7 quads in additional source energy consumption, or 4% to 18% of the total for those end uses (Roth et al. 2004)

Baselines for Measuring Progress

To complement the ZEB assessment and to respond to the PMA requirement to develop a firm baseline against which to measure progress, DOE has initiated a review of the historical advances in building energy codes and a study to establish their long-range technical potential. The potential depends on the frequency and stringency of code updates, the rate of adoption by State and local authorities and the level of compliance. The code analysis results will not only establish the changing baseline over the 20-year period but also provide a basis for evaluating future DOE investments in energy codes. DOE will also assess how current construction practice differs from code requirements to establish an appropriate baseline.

Program Design

To design an effective program based on the results of the Opportunity Assessments, DOE will conduct a series of Program Evaluations. As noted earlier, Program Evaluations consider a wide range of prospective program initiatives to capture the savings defined in an Opportunity Assessment. Program Evaluations typically will consist of the following elements:

- Estimate the potential effectiveness of various types of program initiatives, including research, development, demonstration, deployment and regulation.
- Focus on those opportunities for which research, development and demonstration (R, D&D) are key drivers.
- Consider target market sectors, technology risk, institutional barriers and economics in estimating the potential impact of various program initiatives.
- Consult with other organizations to validate estimates, share results (including with organizations pursuing deployment and regulation options) and identify the potential for collaboration on R, D&D.
- Develop funding scenarios and transition plans for R, D&D efforts. Ensure that selected initiatives and objectives are consistent with an appropriate government role, DOE policy and likely funding levels (do not bite off more than can be chewed).

Filling the Data Gaps

As discussed earlier, there are many gaps in our basic understanding of commercial buildings energy use. Expanding our knowledge base is therefore is a key element of a balanced program, and is also critical to ensuring the quality of BT Opportunity Assessments. It is also important to have a solid understanding of how commercial building energy systems relate to the regulatory, financial and institutional environment. DOE plans will include expanding the knowledge base in these areas. The topics that could be investigated include:

1. energy demographics: characterizing existing patterns of energy use
2. technical and economic performance of systems: component interactions
3. market data: decision-making processes and customer needs

4. non-energy benefits and impacts of HPBs
5. real building performance: field evaluations of HPBs
6. current methods and practices: O&M, commissioning, design methods, etc.

In 2003 and 2004, DOE is conducting work on topics 1, 3, 5 and 6 above to begin to fill in some of the data gaps in current knowledge and specifically to inform BT's opportunity assessments and R&D program design efforts. Work is underway to develop revised sets of prototypical buildings and end-use energy estimates to ensure consistency in all BT commercial building analysis activities. The crosscutting analysis of the High Performance Building case studies (briefly discussed above) will extract results that are common to all case studies and broadly applicable. This will help establish a better technical baseline, add realism to analytical studies and inform R&D agendas. The meta-study on commissioning (discussed above) is beginning to fill the gap in our knowledge in that topic. DOE also completed a recent study to better characterize the structure, operations and decision-making of the commercial building market (Reed et al. 2004).

In addition to gathering new basic data, it is also important to critically evaluate available technical performance and market data relating to whole-building energy technologies and practices. This effort would include assessing the quality, quantity (coverage), reliability and accessibility of existing and emerging data and would identify the critical gaps in knowledge that impede planning decisions. BT would then be better able to formulate plans for plugging the gaps, working together with other organizations with similar needs. (Such an effort is part of the commissioning study previously mentioned.)

Additional Near-Term Actions

In parallel with the intensive planning efforts described above, DOE is taking immediate action to refocus its ongoing activities to support the ZEB goal and to increase the transparency of planning and portfolio management. DOE's recently revised plans now call for adding ZEB capabilities to DOE's EnergyPlus energy simulation software beginning in 2004. The added software capability will support internal analytical efforts and external customers alike.

BT will conduct peer reviews of all of its existing projects to strengthen the project portfolio and support planning efforts. These peer reviews are formal and documented evaluations using objective criteria and qualified and independent outside reviewers. The reviews will be completed by early 2005.

Conclusion

The Nation's 4.5 million commercial buildings consume 18% of the Nation's energy and 35% of its electricity, and have commensurate impacts on environmental emissions. EIA projects that this sector will require an additional 8.5 quads of energy by the year 2025 under its "business as usual" case. The challenges are formidable, and so are the opportunities - but only if commercial building performance can be radically transformed.

DOE's Building Technologies Program has recently developed a long-term goal that is anything but "business as usual", namely achieving the technical and economic potential for zero net energy buildings (ZEB) by 2025. Such ambition requires a focused and systematic approach to R&D planning, especially given the heterogeneity of commercial buildings, the data gaps, and the field-demonstrated difficulty of realizing high energy performance in actual buildings.

In response, BT's Commercial Buildings Program is developing a new strategic framework for R&D decision-making that is responsive to the President's Management Agenda and produces performance measures that are quantifiable, specific and achievable. The essential part of developing a new strategic framework is to identify economically achievable ZEB-focused objectives over time. DOE will establish objectives through two types of analyses: Opportunity Assessments, which characterize and rank the technical and market opportunities for saving energy, and Program Evaluations, which evaluate a range of prospective program initiatives to capture the savings.

A fully realized strategic framework will take time to develop. DOE is also taking near-term actions to refocus its portfolio to support the ZEB goal, and these include: conducting studies to quantify the energy savings potential of commissioning and control systems in existing buildings to fill data gaps; conducting crosscutting analysis of the high performance building case studies to extract lessons learned; and, for several building subsectors, defining the least-cost optimized pathways to achieve various building energy performance levels over 20-year planning horizon.

If successful in realizing the promise of net zero energy buildings, DOE will enhance the Nation's energy efficiency and help bring clean and affordable technologies to the marketplace.

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