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ZERO ENERGY COMMERCIAL BUILDINGS CONSORTIUM

NEXT GENERATION TECHNOLOGIES BARRIERS & INDUSTRY RECOMMENDATIONS FOR COMMERCIAL BUILDINGS

ZERO ENERGY
COMMERCIAL BUILDINGS CONSORTIUM
CBC

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CBC Steering Committee Members

DISCLAIMER

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List of Acronyms

AC	Alternating Current
ANSI	American National Standards Institute
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
BIM	Building Information Modeling (BIM)
BIPV	Building-Integrated Photovoltaics
Btu	British Thermal Unit
CBC	Commercial Buildings Consortium
CCT LED	Color correlated temperature light emitting diode
CEC	California Energy Commission
CHP	Combined Heat and Power
CRE	Commercial Real Estate
DC	Direct Current
DOE	U.S. Department of Energy
ECM	Electronically Commutated Motor
GHG	Greenhouse gas or greenhouse gases
GSA	U.S. General Services Administration
HVAC	Heating, Ventilation and Air Conditioning
IES	Illuminating Engineering Society
LBNL	Lawrence Berkeley National Laboratory
LED	Light-emitting diode
LEED	Leadership in Energy and Environmental Design
MH	Metal Halide
MEL	Miscellaneous Electric Loads
NASEO	National Association of State Energy Officials
NZECB	Net-zero Energy Commercial Buildings
OA	Outdoor air
OASIS	Organization for the Advancement of Structured Information Standards
OpenADR	Open Automated Demand Response
OLED	Organic Light Emitting Diode
PCM	Phase Change Materials
PM	Power Management
R&D	Research and Development
RD&D	Research, Development and Demonstration
SSL	Solid State Lighting
TAT	Thermally Activated energy conversion Technologies
VT	Visible Transmittance
ZNE	Zero Net Energy

Commercial Buildings Consortium (CBC) Overview

In the United States, the buildings sector accounts for approximately 40 percent of total energy consumption and roughly 40 percent of greenhouse gas emissions.[1] About half of this is attributable to the commercial sector, and commercial building energy use is growing more rapidly than residential sector energy.[2] Dramatic improvements in the energy performance of commercial buildings can reduce greenhouse gas (GHG) emissions more quickly and more cost-effectively than many other options, while helping reduce the impact of rising and increasingly volatile energy prices. Transforming energy performance in commercial buildings requires a comprehensive and concerted industry effort, sufficient in scale to influence the more than $600 billion per year that the sector spends on new construction, renovation, and energy.[3]

In response to that need, the Commercial Buildings Consortium (CBC), a public-private, broad-based stakeholder group was established to help achieve near-term results with lasting impacts that can transform the commercial buildings sector to long-term net zero energy goals. The CBC works to capture market feedback on key barriers; identify innovative strategies and successful approaches; and facilitate information and knowledge transfer among stakeholders. Led by a Steering Committee representing prominent national industrial firms, NGO's, and public organizations, the CBC formally launched in late 2009. The National Association of State Energy Officials (NASEO) administers the consortium and serves as its secretariat.

While net zero energy commercial buildings is the CBC's long-term vision, the CBC has primarily operated under the assumption that viable low-energy or net zero energy buildings must first aggressively maximize energy efficiency before integrating renewable energy. Consortium members participate through focused working groups, which paid particular attention to identifying recommendations that can be acted on in the near-term. Rather than adopt a former definition for net zero energy, which is a topic of much debate, the CBC views net zero energy as a directional goal, which helps to concentrate and push thinking beyond traditional approaches. The CBC recognizes that there are many milestones on the pathway to zero and has focused its technology and policy barrier analysis and recommendations on actions in the next 2 to 5 years which can have lasting impacts.

CBC Report Objectives and Development

In its first year, the CBC was tasked by the U.S. Department of Energy (DOE) to compile and assess information on next-generation technologies, systems, and practices and to identify market potential, barriers, and strategic solutions needed to accelerate their deployment and widespread use. The intended audience and beneficiaries of these reports are the commercial building industry stakeholders, and any findings and recommendations are aimed for their benefit and use. In instances where a recommendation has an unspecified audience or actor, the audience or actor is intended to refer to industry partners and stakeholders.

To accomplish this task, the CBC organized its volunteer members into 12 topical working groups. The working groups were divided between Technology & Practice and Market & Policy topic areas, corresponding directly to the technologies and the policy reports, which reflect their deliberations. To

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[1] US Department of Energy, Energy Information Administration. 2010. *Annual Energy Outlook 2010 Early Release Overview.* http://www.eia.doe.gov/oiaf/aeo/

[2] US Department of Energy, Energy Efficiency and Renewable Energy. 2009. *Buildings Energy Data Book*. Building Technologies Program. http://buildingsdatabook.eren.doe.gov. Washington, D.C.

[3] Ibid.

date, over 400 organizational members have signed up overall. Of those, over 200 groups are registered as active members who participate in the working groups. The remaining members participate as associates to receive regular updates on the CBC's activities.

Figure 1: Zero Energy Commercial Building Consortium Working Groups

Technologies & Practices	Market & Policy
1. Building Envelope	6. Codes and Standards
2. Mechanical Systems, Plumbing, and Controls	7. Integrated Design and Building Delivery
3. Lighting/Daylighting and Controls	8. Benchmarking and Performance Assurance
4. Process, IT, and Miscellaneous Equipment	9. Voluntary Programs
5. Combined Heat and Power (CHP), Multi-Building Systems, and Grid Integration	10. Financing and Appraisal
	11. Owner/Tenant Issues
	12. Workforce Development

Source: Commercial Building Consortium

Each working group is chaired by two industry experts. Some groups, such as the Lighting, Daylighting & Controls group and the Benchmarking and Performance Assurance group, further segmented their topic into subgroups and recruited expert volunteers from within the larger groups. Working Group chairs engaged members to provide input through online tools and surveys, conference calls, and webcasts. Over the last year, volunteers from active member organizations participated on over 45 working group calls. Collaboration included sharing resources and information, actively drafting content for the working group reports, and providing comments to outlines and drafts. Each working group developed a report on which the CBC final reports are based. In addition, the CBC drew on existing information sources and literature and evaluated high-performing building projects to identify technologies and barriers.

The results of these efforts are summarized and documented in the following reports:

- *Commercial Building Technologies Inventory*
- *Next Generation Technologies Barriers and Industry Recommendations*
- *Analysis of Cost & Non-Cost Barriers and Policy Solutions*

The CBC recognizes that gaps still remain in the technology inventory and reports to address in subsequent annual updates. The CBC invites its members and other stakeholders to provide comments to these reports. Comments can be submitted to Diana Lin (dlin@naseo.org). Interested parties can also contribute in the upcoming updates by joining as a CBC member.

Introduction

This report summarizes the barriers and recommendations from the five technology working groups of the Commercial Building Consortium (CBC) and is a companion summary analysis to a *Commercial Buildings Technology Inventory.* In development of the *Commercial Buildings Technology Inventory*, the CBC examined existing information sources, including published and gray literature, DOE and National Laboratory plans, industry-sponsored research programs, utility research on emerging technologies, and other sources.[4] The CBC recognizes that there are still remaining gaps in the inventory to address in subsequent annual updates. Additionally, the CBC is aware of a related technology screening effort currently underway through DOE and the National Labs. The CBC intends to provide industry input into that process and build off of results from that technology screening and identification rather than duplicate efforts in the following year to further enhance a comprehensive next-generation technologies inventory.

The scope of the CBC technology activity includes both new construction and existing buildings. Although the a net zero energy commercial building sector is the CBC's ultimate goal, the CBC emphasizes a pathway to zero, which includes achieving substantial near-term energy savings in both new and existing buildings today. This summary highlights barriers in each of the technology areas and provides actionable recommendations that can inform the industry moving forward to a net zero energy commercial building sector in 2050. However, while the goal for net zero energy buildings is long-term, many existing technologies can be refined through further research and deployed in the near to mid-term, and barriers overcome to move the sector substantially toward net zero energy commercial buildings.

Underutilized, existing technologies, and the barriers for deploying them over the next 10 to 20 years, were highlighted by many working groups. The working groups universally cited persisting market barriers to achieving technological goals and recommended policy prescriptions to overcoming many of them. While many technical challenges remain, it is interesting to note the frequency and pervasiveness of market and policy barriers raised by the technology working groups. This indicates that although technological solutions are needed, if existing technologies were more rapidly and fully commercialized, substantial energy savings could be attained while spurring industry innovation for the next generation of cutting edge technologies and products. Both technical and technology-specific market barriers and recommendations are discussed in this report. Additional, policy-oriented barriers and approaches can be found in the CBC companion report, *Analysis of Cost & Non-Cost Barriers and Policy Solutions.*

The CBC Working Groups addressed specific barriers in the following categories:

- Building Envelope;
- Mechanical Systems, Plumbing, and Controls;
- Electric Lighting, Daylighting and Controls;
- Process, IT, and Miscellaneous Equipment;
- Combined Heat and Power;
- Multi-Building Systems;
- Grid Integration; and

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[4] Please refer to Appendix B to see a bibliography.

- Energy Modeling Tools[5]

From the working group discussions, findings, and recommendations, a number of cross-cutting issues emerged from the technology working groups, and they are briefly summarized below. Technology-specific findings and recommendations are included as separate sections in this report.

Cross-Cutting Barriers in Technology Advancement and Adoption

Integrated Design

Major strides in reducing energy use will not be achieved unless integrated design becomes a standard practice and not the niche of sustainable building practitioners. As building systems become increasingly complex, optimizing their interactions and understanding the performance of a building from a holistic perspective is paramount. However, segmented and sequential design and construction processes force developers, designers, and owners towards isolated and insulated decision-making, limiting the ability of downstream actors to optimize energy-saving design features and emphasize whole-building performance. Furthermore, contractors are "rewarded" by lowest initial cost, which leads to value engineering and failure to meet high-performance specifications. Contractors are further deterred from adopting new measures due to complexity and lack of knowledge.

System Integration and Sensors and Controls

Once the building is constructed, achieving high efficiency in practice requires monitoring and automatic controls to ensure that artificial light is available only where it is needed and at the right intensity, for example, and that heating and air conditioning consume the minimum energy required to meet air quality and temperature requirements under changing internal load and outdoor weather conditions. While the underlying electronic information and communication technology has advanced rapidly, protocols and conventions for data compatibility and equipment interoperability are not yet well established. The progress on software development, which is vital for designing sophisticated systems that can be reliably installed in buildings and achieve significant energy savings, has been very slow due to industry fragmentation and lack of agreement on one or more industry-accepted communication platforms. A higher level of sensor and measurement accuracy and reliability, especially the latent component of the load, is needed.

Cost Barriers

Building owners may not accept cost increases associated with net zero energy buildings. Current structures often put a premium on efficiency upgrades with short payback periods. In the instance of lighting systems, this mindset typically does not take into account maintenance costs, light quality, proper illumination levels and distribution or environmental consequences of a lighting technology. Complex modeling tools require specialized expertise and are time-intensive, dictating that only projects with large budgets can afford to use them.

Lack of Skilled Workforce

Lack of education throughout the design community on how to use new technologies and systems hinders adoption of emerging technologies which can achieve substantial energy performance gains. Further lack of familiarity and experience with sophisticated energy modeling tools prevents designers from exploring new and different energy-saving scenarios and options. At the same time, contractors

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[5] Although this is not a separate working group category, the issue of modeling and design tools was singled out by each group as a key barrier and solution and was subsequently pulled out as separate topic for analysis.

also lack training in installing and delivering those new technologies and systems, and building operations and maintenance personnel are not familiar with sophisticated systems. See the CBC *Analysis of Cost & Non-Cost Barriers and Policy Solutions* for specific recommendations on workforce development needs.

Cross-Cutting Recommendations

Expand Research and Development – Not surprisingly, all working groups cited the need for more research and development into emerging and new technologies, as well as ways to streamline the use and integration of these technologies through training of professionals, and case studies that highlight the benefits.

Some overarching R&D recommendations include:

1. Establish a "test bed" for new technologies – a building or site where new products and systems can be tested under conditions similar to actual buildings. The state, regional, and private research programs and the new interagency Greater Philadelphia Innovation Cluster may provide the opportunity to study the technical issues raised in this paper. State of the art sensors and data collection equipment should be integrated into the building to expedite test and measurement procedures. This site could also be used to train building operation personnel in the installation, use, and maintenance of new advanced systems. Conduct occupant and behavioral research for high-performance buildings.
2. Carry out rigorous studies and post-occupancy evaluations to assess the potential for productivity gains and reduce employee health and absenteeism costs from enhanced indoor environments enabled by high-performance building envelope systems. Analyze how savings on operations may affect the building value and re-sale value.
3. Develop comprehensive behavioral research program to quantify behavioral benefits and value of varying component, system, and control strategies for current and future technologies. This would include lighting, daylighting, HVAC, and plug loads.

Develop and Disseminate Case Studies

Research demonstrations should be well-documented in case studies and disseminated widely to stakeholders. Specifically, develop and disseminate best-in-class design and construction details, cost-benefit analyses, and rigorous demonstration projects for all of these technologies, systems, and sub-systems to demonstrate their viability to architects, engineers, and building owners. The projects included in these analyses should come from a range of climate zones, building types, and new and retrofit projects.

Explore Direct Current (DC) Power Applications - Electricity is currently supplied to lights and controls equipment in the form of alternating current (AC). DC micro-grids would fundamentally change the way power is supplied in commercial buildings, eliminate AC-DC conversions at the equipment level, simplify equipment designs and layouts, provide improved interfaces with renewable energy sources and storage, and save energy.

Specific recommendations include:

1. Technical assessment of requirements is needed to derive the specification for DC micro grids.
2. The micro-grid architecture needs to address emerging lighting (e.g. solid state lighting or SSL) as well as internet connected appliances while clearly pointing out the benefits in terms of energy savings, lifecycle cost-savings and flexibility.

3. Develop standards on voltages and other conventions.

Promote Multi-Building Systems – Net zero energy commercial buildings may prove difficult to impossible to achieve on a building-by-building basis except where conditions are particularly favorable and account for excess generation or storage of on-site energy. More likely, net zero energy will generally be achieved in multi-building systems that are responsive to generation and load signals. More specific barriers and recommendations can be found in the Multi-Building Systems section.

Shift to an Integrated Design Process

Move away from current prescriptive building energy codes, which run contrary to the integrated design process envisioned for net-zero energy commercial buildings (NZECBs) that emphasizes system- and whole building-level savings, to performance-based codes. See the CBC *Analysis of Cost & Non-Cost Barriers and Policy Solutions* for more specific recommendations on integrated design and building delivery.

Improve System Integration and Sensors and Controls

As commercial building technologies and systems become ever more complex and sophisticated, system integration is essential. Many of the failures in modern buildings today can be traced back to system integration failures.[6]

Recommendations include:

1. Require new and meaningful metrics to properly characterize the performance of the systems. Promote recognition of these metrics by utilities and other entities for incentive verification.
2. Develop a suite of standardized protocols, data structures, control parameters, interfaces and interoperability profiles for communications and information exchange between individual components and subsystems. Strategic partnerships, collaboration and cooperation cutting across industry domains, academic and governmental institutions, regulators and policy makers are essential to this process.
3. Increase the rigor and frequency of building commissioning and retrocommissioning. Substantial experience in state and local buildings has demonstrated enduring energy savings resulting from commissioning.
4. Evaluate the potential for *in situ* sensors that could enable or facilitate initial and continuous commissioning of new or existing building envelopes.
5. Develop standardized control packages and solutions to effectively operate these high-performance complex systems; these could come from greater use of centralized monitoring and control (including remote operations).
6. Provide advanced software for prognostics and diagnostics of the building operation. The overall control system should have a visual display with the key metrics in full view. These metrics should be relevant to those monitoring the system (i.e. energy use, financial ROI, data points, maintenance and diagnostic tools).

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[6] Selkowitz, Stephen, Jessica Granderson, Jeff Harris, Philip Haves, and Paul Mathew. 2008. *Scale Matters: An Action Plan for Realizing Sector-Wide "Zero Energy" Performance Goals in Commercial Buildings*. http://escholarship.org/uc/item/1kf4t1nh. Berkeley, Calif: Lawrence Berkeley National Laboratory.

Building Envelope

The move to net zero-energy buildings will require building envelope systems to provide superior performance over a wider range of conditions than in typical commercial buildings today. Although significant changes will occur in building envelope components, transformative technological improvements are envisioned at the system level. Commercial building design and delivery process will also need to change significantly to facilitate delivery of high-performance and cost-effective envelope systems. Technology and process developments will be needed to achieve a vision of pervasive net zero energy commercial buildings.

General considerations that permeate Building Envelope technologies include the need to:

- Develop high-performance and cost-effective building envelope commissioning technologies.
- Implement a coordinated approach by the design and construction team using a quality control and quality assurance processes such as building envelope commissioning and retrocommissioning.
- Encourage large tenants such as major corporations or public agencies to take the lead on implementing building envelope commissioning on their projects.
- Develop case studies documenting the cost and benefits of the process to show how the process works, and show where it does not work.

Evidence suggests that high-performance building envelope systems are more sensitive to improper installation than conventional systems. For example, water is less likely to accumulate over time in a poorly insulated wall system than a high-performance wall due to the larger thermal energy flows through the poorly insulated wall system. Furthermore, more favorable building envelope economics depend on cost-savings achieved from down-sizing mechanical systems due to better insulation. If the envelope is not constructed properly, it results in either an HVAC system that cannot meet the higher-than-designed space conditioning loads or diminishes the degree of down-sizing (and cost-savings) that engineers are willing to specify. Unfortunately, challenges exist in identifying a single entity with responsibility for envelope quality/performance and problems with existing building enclosures are not usually detected until they have reached a point where the symptoms become apparent to building occupants (e.g., visible mold growth, bad odors, visible water damage or stains, etc.).

Widespread deployment of cost-effective NZECBs will require extensive research, development, demonstration and deployment of a wide range of building envelope technologies. Many of the technologies for achieving NZECBs exist in some form today, but are too costly, lack a sufficient track record for design and delivery professionals and building owners to implement, or are poorly understood by codes officials. Analysis is organized in three major areas: Opaque Envelope; Fenestration; and Building-Integrated Photovoltaics (BIPV).

Envelope system integration includes integration of window, wall, and roof system design and control with that of other envelope in building systems, mainly mechanical moveable shading products (exterior louvers, double-skin curtain walls with integrated automated blinds etc.), external fixed shading, interior lighting systems, and HVAC systems. To achieve the vision of net zero energy buildings, windows must undergo significant innovation in three different areas: 1) Fixed glazing; 2) Dynamic glazing, and 3) Window system integration. Dynamic glass, i.e., glass with variable visible transmittance (VT), can enable close to real-time optimization of solar heat gains and glare management through windows. Implemented and controlled properly and maintained, together these systems can dynamically optimize solar heat gains to reduce lighting and HVAC energy consumption while also effectively managing solar glare. Though a standard of design in European buildings, in practice such integration is challenging.

BIPV integration into new and existing building envelope systems will be an important element in achieving widespread NZECBs, most notably for buildings that cannot meet their energy needs from the available roof area (due to either building height or high energy demand).

Barriers

Opaque Envelope (Walls and Roofs)

1. Inadequate thermal performance of opaque walls and roofs impairs the potential reduction of thermal bridging caused by framing members and/or increased R-value of the continuous insulation. Insulation systems with high thermal resistance per unit thickness can minimize these problems for both interior and exterior insulation systems, but are still costly and can have attachment / installation and potential long-term durability challenges.
2. Phase-change materials (PCM) integrated into building envelope materials have the *potential* to reduce heating and cooling energy use, but have not been independently demonstrated to reduce energy use cost-effectively, and their application/specification is not understood by the majority of the building industry. The community needs validated software tools to evaluate, design, and select building envelope materials incorporating PCMs. Support should be provided to determine the potential for PCMs to reduce energy use in commercial buildings.

Fenestration (Windows and Frames)

Fixed glazing

1. Window and glazing manufacturer R&D is needed to simultaneously achieve much higher quality, performance, and lower cost.
2. In existing buildings, in order to increase thermal performance in the glazing, triple pane glass may be required, but existing frames often cannot accommodate the increased glass thickness and would need to be replaced too, increasing cost. Consequently, windows that achieve high performance within a limited thickness and can fit into existing frames have particular value for renovation of existing buildings.

Dynamic glazing

1. A limited number of products with dynamic glass are currently available on the market, but their current cost prevents widespread use.
2. Integration barriers include lack of holistic design and operations approach and lack of education in design community.
3. Cost-effectiveness, real or perceived reliability concerns, and aesthetic concerns remain.

Electrochromic Windows

1. The durability of some electrochromic films, particularly liquids, is still not known. Development of a compound that improves durability, is less costly, and solves technical problems related to the ion-storage layer is needed.

Building Integrated Photovoltaics (BIPV)

1. BIPV products are not widely available and not cost-effective in most building applications.
2. When integrated into walls or windows, BIPV usually produces significantly less electricity/year than conventional PV panels.
3. BIPV tend to have lower reflectances than most building materials, which increases surface temperatures. In turn, this increases building air-conditioning loads and decreases PV output, and may also have the potential to adversely impact roof durability.

Industry Recommendations

Opaque Envelope

1. Develop insulation materials with high thermal resistance per unit thickness (e.g., R≥10/inch) with competitive cost effectiveness for mainstream building applications.
2. Independently evaluate performance of PCM's and develop, test, and validate software to allow designers, architects, and engineers to evaluate, design and select building envelope materials incorporating PCMs appropriately. Ensure effective integration with insulation materials.

Fenestration

Fixed glazing

1. Develop high-performance (e.g., R~10) and durable windows that is cost effective for widespread application in commercial buildings.
2. Conduct field tests and studies for longevity of 3 or more pane units to reduce real and/or perceived application risk.

Dynamic glazing

1. Develop dynamic glass products that are cost effective for widespread application in commercial buildings.

Window Systems Integration

2. Conduct evaluation and review of building envelope practices in Europe to understand why dynamic solar control has become a standard part of building design.
3. Develop an industry roadmap or plan to accelerate the adoption of such products, including development of systems that are cost-effective for widespread application in commercial buildings.

Building Integrated Photovoltaics (BIPV)

1. Develop cost-effective BIPV products that effectively leverage the oft-discussed installed cost benefits from integration of PV into building enclosure components and systems.
2. Carry out studies to evaluate the long-term thermal and electric performance and durability of BIPV products relative to conventional building enclosure components and systems.

General Recommendations

1. Develop templates of robust specifications of building envelope components and systems commonly used in NZECBs to address obstacles such as substitutions.
2. Use data developed from envelope commissioning to clearly identify where the most common and severe shortfalls in building envelope system design and construction; ensure feedback of these findings to design and construction professionals to avoid future problems.

Mechanical Systems and Controls

This section of the report addresses mechanical systems and equipment that incorporate the Heating, Ventilation, and Air Conditioning (HVAC), and the controls for operation and optimization of a building that will contribute to the goal of net zero energy use in buildings. Achieving net zero energy requires maximizing the efficiency of all building systems and meeting remaining energy demand needed to operate the building with renewable energy sources.

Simply put, to achieve net zero energy buildings, the approach to mechanical systems architecture must be changed. Moving mechanical systems to net-zero-energy commercial buildings (NZECB) will rely strongly on an integrated design process. Unless a new and integrated approach to building delivery becomes the norm, net-zero energy cannot be obtained in the foreseeable future. The entire industry must transform to embrace a methodology that revolves around drastically increased integration of thought, design, systems and controls than ever before. Further, to ensure that NZECBs perform as designed will require significant changes to initial and continuous commissioning.

At the technology-specific level, it is striking that while a solid core of efficient heating and cooling technologies that are in full-scale production and use can be used to implement a net-zero energy commercial building, a large number of commercially available technologies that can provide additional, cost-effective energy savings are markedly underutilized. A significant number of technologies are still in either the emerging or developmental stage that could contribute further to energy savings in appropriate applications.

Additionally, a greater degree of control sophistication and “smarts” will be needed to combine optimally free, recycled and stored energy while operating powered equipment needed for remaining loads at maximum efficiency. Controls will also play an important part in the commissioning and retrocommissioning of the building. A widely recognized problem is that buildings often do not operate as designed. Much of this variance results from oversights and errors in initial commissioning and on-going maintenance. Advances in controls and software, as well as sub-metering, are a very effective way to improve in this area.

The control technologies are important because the effective coordination of stored, reused, and free heating and cooling sources with efficient mechanical systems will require a higher level of controls integration. The ability in real-time to optimize the operation of multiple systems, to anticipate and exploit changes in conditions, and react to changes in occupancy offer the potential for significant energy savings, while delivering a high level of occupant thermal comfort. In addition, intelligent controls can recognize a variety of energy-wasting fault conditions and either correct them directly or notify the building operator that corrective action is necessary.

Barriers

Underutilization of existing technologies

A significant number of underutilized commercially available technologies can contribute to the net-zero energy goal sooner rather than later (See Figure 2). These underutilized technologies are available now for use in appropriate net-zero energy designs; however if they were more widely utilized, they would probably be lower in cost and therefore more cost-effective to use. In addition to the cross-cutting barriers discussed in the introduction, the following is a brief list of market barriers:

1. Short term payback mentality.
2. Lack of federal government encouragement.
3. Lack of recognition in standards/codes.
4. Metrics for systems/part load.
5. Lack of exposure, lack of education.
6. Emerging technologies are never a core technology until large HVAC companies with large channel distribution adopts them.
7. Contractor base dedicated to core, mainstream technologies due to cost, complexity, lack of knowledge.
8. Plan/specification contractors are not prone to embracing integration and energy optimization.
9. Modeling programs do not include all of these technologies.

Emerging/Developing Technologies

Market barriers in emerging and developing technologies are:

1. Lack of involvement by capital investment community[7].
2. Short-term return on investment focus vs. life-cycle cost return considerations.
3. Minimal understanding of how systems and operations contribute to the asset value of the building/complex.

Industry Recommendations

For Undertilized Technologies

1. Development and support of system metrics used to characterize the actual efficiency/ performance.
2. Integrated design, rebates and other incentives, education and updated codes and standards that define the end requirement or outcome rather than the technical solution.

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[7] For more information on the role of the capital investment and financing community, please refer to the Financing and Valuation section of the CBC companion report, *Analysis of Cost & Non-Cost Barriers and Policy Solutions.*

Figure 2. Underutilized and Emerging Mechanical System Technologies

Primary Function of Technology	Underutilized Commercial Technologies	Emerging/Developing technologies
Recover/Reuse	Commercial Energy Recovery Ventilation Systems Integrated Energy Recovery Ventilation Systems Air Handler Integrated Energy Recovery Ventilation Systems Unitary Commercial Ground-Source Heat Pumps Distributed Energy Recovery of Process Waste Heat Heat Pipe Off peak Cooling and Heating coupled to thermal storage	Commercial Ground-Source Heat Pumps Centralized Earth Tube Ventilation distribution system Solar Power Concentrators - passive.
Minimize Natural Resources	Water/air/refrigerant Economizer (Free Cooling) Solar water heaters Solar thermal space heating	
Energy Storage	Cool Storage Integrated Lighting / HVAC Controls.	Advanced Thermal Storage Materials/Systems-Building Thermal Mass
Efficiency	Advanced Fan/Blower Technologies Commercial Ductwork Optimization Electronically Commutated/ Permanent Magnet/Brushless DC Motors Hybrid systems Improved Duct Sealing Radiant Heating/Cooling Variable capacity equipment for Heating and Cooling as well as staged multiple units Variable-Speed Drive Building Automation System Air to water heat pump chillers Commercial condensing boilers Dedicated Outdoor Air Systems Point of Use Water Heating Water to water heat pump chillers Active Chilled Beam Cooling with DOAS Variable water Flow Systems Alternative Air Treatment (to reduce OA) Desiccant Dehumidification Systems Microchannel Heat Exchanger Underfloor air distribution Variable Refrigerant Volume/Flow Mechanical Insulation Systems (HVAC, Piping , Equipment, Boilers etc) Electric motors with integrated variable speed drives	Commercial heat pump water heaters Commercial Hot-Dry Air Conditioners Customization of Unitary HVAC Equipment Dehumidification Enhancements for Air Conditioners in Hot-Humid Climates Evaporative Cooling Indirect Improved air side zoning systems Right Size HVAC Equipment Advanced Compressor Variable/High Speed Advanced Northern Heat Pumps Advanced vapor compression cycles Displacement Ventilation Evaporative Heat Rejection Unitary High Efficiency "Gas-Pack" Rooftop Packaged Air-Conditioner Liquid Desiccant Air Conditioner Modulating Furnace Next Generation Refrigerants Pond Based Ground Source Heat Pumps - Cooling

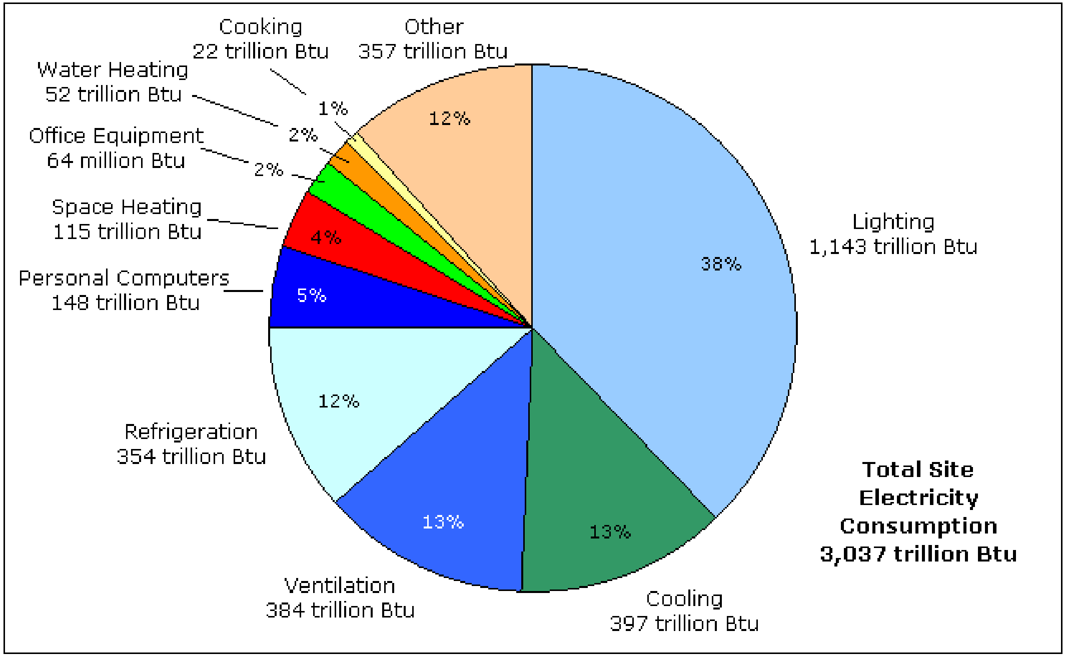
Primary Function of Technology	Underutilized Commercial Technologies	Emerging/Developing technologies
	Centrifugal pumps with ECM motors **Centrifugal pumps with integral motors and variable speed drives** **Zone instant hot water heaters**	
Controls	**Automated Fault Detection and Diagnostics for Rooftop Units** **Complete/Retro Commissioning**	**Adaptive/Fuzzy Logic Controls** **System/Component Diagnostics** **System/Component Performance Diagnostics** **Zonal Ventilation/Control** **Personal Thermostat (e.g. Ring Thermostat)** **Microenvironments / Occupancy-Based Control** **Centrifugal pumps with ECM motors and intelligent controls** **Open loop day time hot water Solar Heating / Night - Instant hot water heating.**

Source: CBC Mechanical Systems, Plumbing and Controls Working Group

Lighting, Daylighting and Controls

Gains in energy efficiency can be achieved today through proper training and operational procedures by building personnel. The proliferation of existing technologies offers a tremendous opportunity as well, especially as more site electricity is consumed by lighting than any other category (see Figure 3). For example, the implementation of lighting control technologies that exist today can reduce lighting electrical energy by 40% or more. However, for Net-zero Energy Buildings to become a reality, building owners must be convinced to invest in new technologies and systems, as efficiencies to be gained by individual electrical components are limited. This point becomes even more significant as buildings become more sophisticated.

Figure 3. Commercial Building Energy Consumption by category



Source: Energy Information Administration, 2003 Commercial Buildings Energy Consumption Survey, Table E3.

The ability to achieve a net-zero energy building based on improvements in lighting will, to a large extent, be determined by the configuration of the building itself. Merely changing out inefficient lighting for more efficient lighting can achieve tremendous gains in reducing the energy requirements of a building, however, the most energy-efficient lighting is that which can be turned off or reduced when not needed. Furthermore, merely lighting a building is not enough; the lighting must not detract from the function of the building and the support of the occupants' tasks. Thus, any technological solutions that move toward a net-zero energy building must provide ***both*** the quantity of light required by the tasks and the quality of light that allows for the comfort, productivity, and safety of the occupants. It is short-sighted to consider the energy that could be saved by using low-quality lighting, such as high correlated color temperature (CCT) LED lighting, but no one wants to work under bluish lighting with poor color rendering. Savings provided by poor quality light are also illusory since the higher quality the light, the less light that is needed and the more productive people are under the light.

Below are some overarching observations:

- Traditional light sources do have a place in net-zero energy buildings, but to a limited extent. High-efficiency fluorescent systems for general lighting and improved performance metal halide for higher ceilings, atria, small auditoriums, etc. should be considered as part of an overall lighting design.
- The major portion of the lighting work will need to be done by some form of improved solid state lighting due to its high-efficacy, long-life, and ability to control.
- New lighting design techniques and software will ensure the significant lighting demands of net-zero energy buildings are met.
- NZECBs will depend heavily on improved designs and application of Daylighting and Control Systems.
- Buy-in from building owners is paramount.
- Even though the target is 2030, product development cycles will dictate that the real timeline is shorter, perhaps 2020 or 2025. New technologies require extensive testing both at beta test sites and under real world conditions. As referenced in the introduction, a "test bed" is crucial for understanding the performance of new technologies and accelerating their market acceptance, while simultaneously offering the benefit as a training site.

Daylighting use is critical if we are to achieve huge leaps in building energy efficiency. Significantly reducing use of electric lighting through daylight distribution and management, as well as integration with lighting control systems, will substantially support net-zero energy goals. This should be achieved without compromising other aspects of building envelope performance including managing direct solar heat gain and heat transfer through other building envelope materials. Furthermore, actual building energy performance as measured in Btu per square foot per year must be measured and reported. Simulated and installed equipment data is not enough. Improved occupant comfort, productivity, and well-being through access to natural light needs to be achieved, and architectural design and aesthetic intentions should be supported through use of natural light to enliven building form, interior spaces, and materials.

At present, lighting control systems are typically not well-integrated. Energy savings from daylighting is not possible without well-integrated controls. Proper use by building managers and building users is a challenging issue. Products in early stages of commercialization such as electrochromic glazing have recently become commercially available, but have not yet been widely adopted. Although recent advances in energy codes and the accelerated adoption of sustainable design practices for federal buildings have slightly improved the penetration of lighting controls in new construction, their full energy-saving potential is far from being realized in all construction types. Despite the availability of today's cost-effective lighting control technologies, most buildings have not been upgraded or have been improved only marginally. Implementing lighting control technologies that exist today can reduce lighting electrical use by 40% to 60%, or more. Integrated lighting control strategies that exist today can significantly reduce lighting energy consumption in a commercial building. Furthermore, using lighting controls benefits whole-building energy performance because as electric light output and energy are reduced so is the overall cooling load on the building's HVAC system.

In the future, automated continuous commissioning tools would be designed to track real-time performance of lighting system, detect anomalies causing energy waste, identify any faults and diagnose any system level problems. Thus, the paradigm will shift from reactive maintenance to cost-effective proactive maintenance. Selecting the right product, or system, for a project, and ensuring correct installation, set-up and commissioning are all crucial to the successful implementation of lighting control systems. Some of the biggest barriers to successful applications are faced in these areas.

Additionally, inter-system coordination between lighting controls and the overall building automation system is also imperative. Standardized protocols need to be adopted. For example, communications between lighting control systems and the systems that manage HVAC and the motors that run the escalators/elevators should be able to work together. Furthermore, integration between the building and the smart grid will create a new future in energy efficiency. The use of “smart systems” that do not require human intervention will ensure maximum benefit is realized at all times.

Cross-Cutting Barriers

1. Proper light levels in net-zero energy buildings are not agreed upon.
2. Contractors are "rewarded" by lowest initial cost, which leads to value engineering and breaking high-performance specifications.
3. Occupant comfort and safety – building occupants may not feel comfortable working under new lighting systems, and insurance underwriters may insist on brighter illumination.

Cross-Cutting Recommendations

1. Conduct research to determine appropriate illuminance for these types of buildings, i.e., buildings with major amounts of daylighting, lighting dimming controls, etc. Also, it would need to be determined if occupant comfort and safety are adequate for their tasks.
2. Develop new lighting design techniques to account for the changes in lighting systems, e.g., how to handle transition areas from daylighting to electric lighting, new control strategies, etc.
3. Develop strong degree programs and effective continuing education curriculum emphasizing daylighting and controls and overall building performance in architecture, engineering, building science, construction, real estate, and building operations.
4. Determine consensus standards for adequate light levels in net-zero energy buildings.
5. Standardize methods for measuring the performance of lighting control technologies over time. This is critical for auditing, benchmarking, performance comparisons, reporting and documentation.

Specific barriers and recommendations in the three categories of Electric Lighting, Daylighting, and Controls follow below.

Electrical Lighting

Barriers

Product-specific

1. Metal halide (MH) lamps need longer life and improved efficacy in low wattage (< = 150W). They cannot dim below 50%; and MH electronic ballasts need improved performance and low level dimming capability. New radiating materials are needed for environmentally friendlier lamps that do not use mercury or other toxic materials.
2. LED (white light) efficacy is too low.
3. OLED (white light) life and efficacy are too low.
4. Inadequate standards for solid state lighting (SSL).

Industry Recommendations

1. Conduct research to improve performance of metal halide lamps, including dimming capability and improved, performance-matched electronic ballasts.
2. Develop a plan to improve efficacy and color stability of LEDs.
3. Perform a study to determine ultimate capability and applicability of OLEDs. If positive, then research will be needed to achieve goals of longer-life and higher efficacy.
4. Develop valid life-test methods. The market will not wait for traditional life-test results of very long-life sources.
5. Establish ANSI/IES standards for performance and electrical compatibility of SSL.

Daylighting

Barriers

Product/system technology

1. The performance of films and coatings for glazing must be higher and more cost-effective.
2. Daylight distribution systems are inefficient or cumbersome.
3. The need for improved building envelope materials (insulation, infiltration, durability) is pervasive.[8]
4. The high cost of daylighting systems creates barriers to acceptance.

Software and design techniques

1. Daylighting needs may conflict with other building envelope strategies - particularly solar control and insulative properties.
2. The current ASHRAE advanced design guides do not include dynamic systems.
3. Better daylighting metrics are needed. For instance, LEED criteria for daylighting are very simplistic.
4. There is often a chasm between daylighting objectives, decision-making, and daylight conditions in completed buildings. In part this is because there is seldom an incentive for evaluating actual conditions. Control systems are often installed but may not be well designed or properly commissioned to realize daylighting energy savings potential.

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[8] See Building Envelope section for more detail.

Industry Recommendations

1. Better integrate daylighting analysis in the design and documentation process. The daylighting designer needs to be at the table earlier in the process and needs to interact with the building envelope designer and the interior designer.
2. Develop single comprehensive study or a series of coordinated studies documenting the theoretical and actual performance potential of overall building configuration and envelope systems on daylighting, energy use, and human factors would be very valuable.
3. Increase research and development of building materials and systems to improve daylighting distribution and glare management. This should include exterior systems, interior systems, films and coatings applied to glazing, and systems that are installed within glazing units.

Lighting Controls

Barriers

Occupancy and Daylight Sensors

1. Both occupancy and daylight sensors are still often misapplied and incorrectly installed and commissioned, which leads to occupant and building owner complaints.
2. Although the cost of the photosensor is not prohibitive, it must operate with a dimming ballast, which is the most expensive component in the system.
3. Guidance for placement varies among manufacturers and products, and manufacturer guidelines must be strictly followed to ensure performance, making determining sensor location along with set-up and commissioning an issue.
4. Systems often need to be “tweaked” to account for seasonal variation, or to suit occupant preferences, and this usually requires additional site visits, typically after construction is complete and the building has been occupied for some time.
5. Personal controls are not widely used because they are viewed as a superfluous expense, rather than as an energy saving tool. Although the energy saving benefits of personal control has been fairly well-documented their energy-saving benefit and overall value has not been well understood, or communicated to owners and end-users.

Intelligent Lighting Controls, Advanced Sensors and Networked Controls

1. Lack of universal standards for integrated lighting controls has already led to a fragmented market full of high-cost, proprietary and incompatible solutions, and the shortage of skilled professionals, which slows adoption.
2. Despite many virtues of wireless technologies (e.g. cost-effective deployment in legacy building where rewiring could be cost prohibitive), the lighting control industry has been slow to embrace it due to reliability interference, and cost concerns.
3. Few technologies exist today that elegantly turn plug-loads (such as plug-in portable lamps) off when not needed.
4. Existing simulation tools are inadequate to handle the complexities of the advanced lighting control technologies and interdependencies among integrated systems.

Design, Application, Installation, and Market Acceptance

1. Design and specification obstacles prevent lighting controls from being fully utilized, which ultimately limits the magnitude of achievable savings. Designers spend their time researching

energy codes for projects, rather than spending time designing the most effective, and efficient solution. On the design side, principles have not been firmly established regarding occupant acceptance of the level and rate of dimming.

2. Technical system performance issues such as lamp/ballast compatibility and efficacy remain major concerns.
3. Most lighting control systems wiring is complex, especially when there are many control zones tied to multiple sensors and switches. Newer control technologies exist that mitigate wiring complexity, and minimize installation and set up time (e.g. digital control, wireless); however, the benefit of these technologies is not widely known.
4. Many building owners and design team members do not believe that lighting control systems are reliable yet. This may well be a misconception, and perhaps a function of how well commissioning is done. It is imperative that the reliability of such systems is demonstrated so that they are widely accepted and their efficacy is proven.

Industry Recommendations

1. Establish an initiative on emerging lighting control technologies with broad industry representation, which focuses on the development of next-generation lighting control systems and technologies for getting to net-zero energy, such as smart sensors, adaptive lighting principles, and systems.
2. Industry collaborations should provide large-scale wireless lighting control demonstration projects in the sector to help alleviate scalability and integrity concerns and establish wireless technology as a reliable solution for connectivity. Proven cost-effective wireless technology, improvements in energy harvesting sensors and advances in battery technology are needed to make wireless a viable choice for lighting controls. Breakthroughs in high- performance low-power radios and scalable network architecture could expand the coverage of wireless lighting controls networks to the entire building.
3. Develop novel demand management strategies and simulation tools focusing on lighting controls and pilot programs quantifying performance and strengthening the role of lighting controls. Research and cooperation among industry stakeholders is needed to define the information models for real-time information exchange between lighting systems, utilities, and the smart grid.
4. Establish an industry stakeholder panel on smart grid lighting integration that will coordinate with existing industry smart grid panels to ensure that all relevant characteristics of existing and future lighting and control systems are built into a lighting information model for integration with a smart grid.
5. Develop lighting controls design and application software integrated with common lighting design software. This software would work with current lighting calculation and modeling software and Building Information Modeling systems to calculate and model lighting control system energy performance, impacts on other building systems, and economics.
6. Develop an industry-accepted one-stop web portal for finding lighting control solutions, technologies and applications.
7. Develop self-configuring standardized protocols and advanced tools to make the process of installation and commissioning friendly to non-experts, and easy for electricians.

Process, Miscellaneous Equipment and IT

Miscellaneous Electric Loads (MELs) represent a significant and growing portion of the commercial building load (see Figure 4). The greatest technical potentials in this area are in water heating and IT/office equipment. Technical potentials for laundry, pool heating, and appliances are also significant. However, as noted in Figure 4, the highest MELs ranked by electric load offer a different subset of priorities. Our summary highlights technological barriers from both subsets.

A high level of industry coordination and standards setting will be required to achieve net-zero energy goals. Barriers to implementing energy-efficient technologies include lack of information on equipment, higher upfront costs, maintenance, reliability and operational constraints. Additional concerns relating to the deployment of energy efficiency equipment includes the turnover of stock of equipment in existing buildings.

The Miscellaneous Equipment, Process and IT working group found a recent report to the DOE Building Technology Program on *Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances* [9] by Navigant Consulting, as well as the TIAX report[10] characterizing energy consumption in commercial miscellaneous electric loads characterization and savings potential particularly informative and commended them to the CBC. At the suggestion of the working group, rather than duplicate previous efforts and research, much of the information contained in this summary cites these reports. According to the Navigant report, there is an opportunity to accelerate the development and adoption of energy-saving technologies in a number of ways, including the establishment of new and revised energy efficiency standards, support of demonstration activities for emerging technologies and of research and development for advanced technologies. Based on the findings from those reports, the CBC has identified and highlighted some areas that industry stakeholders can explore to seek opportunities for partnership and advancing commonly shared objectives.

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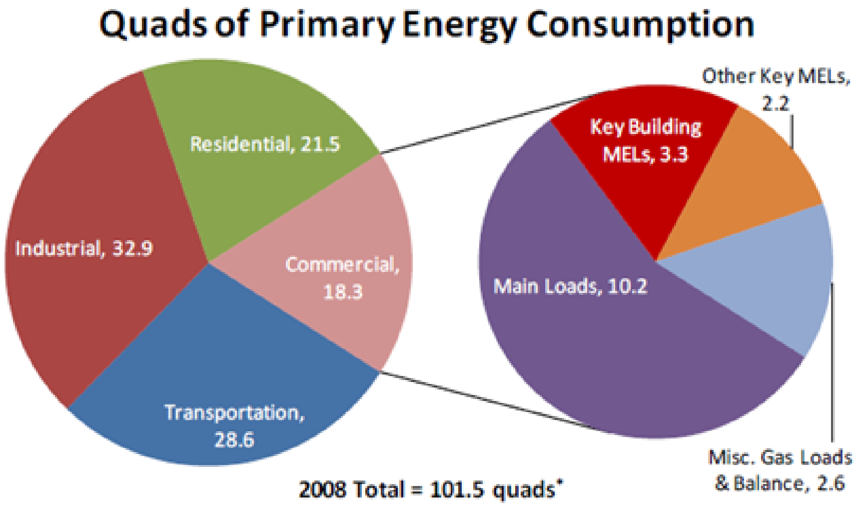
[9] Navigant Consulting, Inc. 2009. *Energy Savings Potential and RD&D Opportunities for Commercial Building Appliances*. Washington, DC: US Department of Energy.. http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/commercial_appliances_report_12-09.pdf

[10] TIAX LLC. 2010. *Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type.* Washington, DC: U.S. Department of Energy, Building Technologies Program.

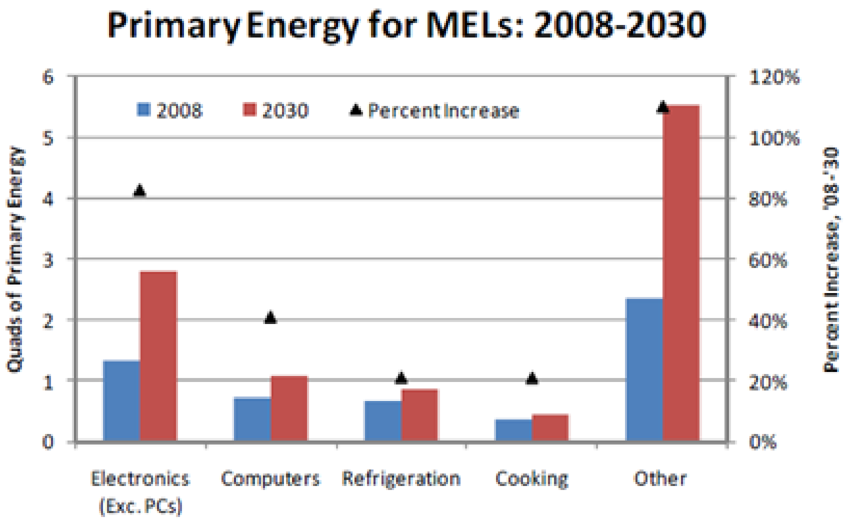
Figure 4: Quads of Primary Energy Consumption[11]



The CBC working group prioritized the largest loads first, and used the 2008 actual and 2030 estimated energy consumption (Figure 5) to guide priorities. A second chart shows key building MELs are shown below (Figure 6) in order of estimated energy consumption. From this chart, one can see that Electronics, Refrigeration and Cooking the top three single energy loads. The largest category, "Other," in Figure 5 is a collection of a variety of energy loads and is forecasted to grow at the fastest rate.

Figure 5: Primary Energy Consumption Projections for MELs[12]

MEL primary energy consumption is projected to increase by 78% between 2008 and 2030.



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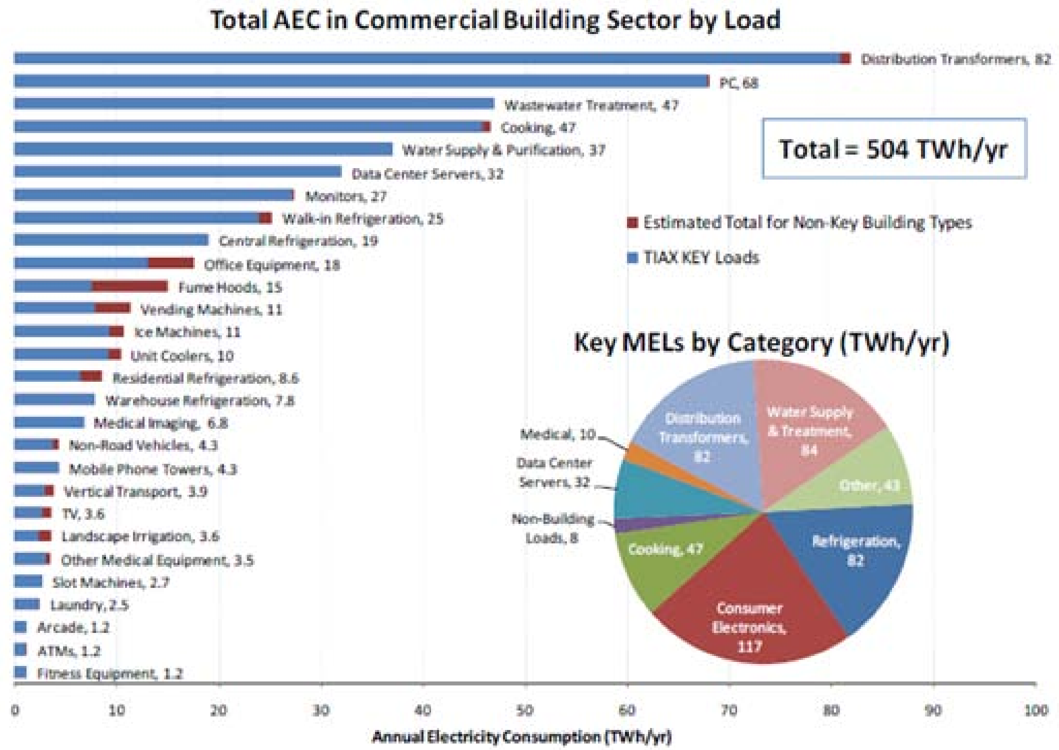
[11] TIAX LLC. 2010.*Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type. Figure 1.* Washington, DC: U.S. Department of Energy, Building Technologies Program.

[12] TIAX LLC. 2010. *Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type. Figure 6.* Washington, DC: U.S. Department of Energy, Building Technologies Program.

Figure 6: Total Annual Electricity Consumption in Commercial Buildings by Load[13]



Barriers

Automation - Both the Navigant Consulting and TIAX reports suggest MEL Automation has a huge potential to reduce energy consumption. Technical challenges and factors that make the automation of MELs difficult include the diffuse nature of MELs, their large and disperse installed bases, and diverse usage patterns in their various modes of operation, and interoperability requirements. Additionally, various human factor issues in terms of usability and ease of installation need to be considered to ensure ease of usage compliance and maximize energy savings.

Power Management (PM)[14] - There are various barriers to achieving a higher use of PM, including: inconvenience associated with longer boot-up times, need for remote access, need to run computing jobs while the user is away, and, perhaps most importantly, insufficient economic incentives. The issue of savings associated with PM may be a greater challenge in a commercial setting, since the users are typically not directly responsible for their company's energy costs.

Water-Heaters[15] - Service water heating accounts for a large portion of the energy consumed in commercial buildings, and has a high savings potential. Common barriers among emerging water heater technologies include extensive retrofit issues and high first cost of equipment.

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[13] TIAX LLC. 2010. *Commercial Miscellaneous Electric Loads: Energy Consumption Characterization and Savings Potential in 2008 by Building Type. Figure 4.* Washington, DC: U.S. Department of Energy, Building Technologies Program.

[14] Power management includes strategies that place devices into a low-power "sleep mode" or off mode after a period of inactivity.

[15] Water Heating technologies are included in the Technology Inventory Matrix under Mechanical Systems, Plumbing, and Controls.

Condensing Water Heaters - High first cost and retrofit limitations (e.g. new flue, drain access, installation concerns among plumbers).
Heat Pumps (heat pump water heaters of all refrigerant types) - High first-cost relative to standard water heaters; lack of knowledge partly due to lack of manufacturer marketing
Solar Thermal Water Heaters - High first cost; reliability concerns; product availability; insufficient contractor training; lack of field experience
Absorption Heat Pump Technology - while scalable for most commercial applications, but due to high first costs it tends to be more economical for installation in facilities with high water heating demands. Additionally, emerging technology; retrofit limitation; consumer/industry understanding; shipping/installation limitations for ammonia (the working fluid) all pose barriers.

Refrigerators - Equipment buyers are under pressure to keep upfront cost low, reliability high, and refrigerated space maximized. In some segments such as vending machines and beverage merchandisers, the equipment is often specified and provided for free to the customer by a bottler or vending machine operator who does not pay the energy bill and thus has little incentive to specify high efficiency equipment. In addition, across many segments, there is limited awareness of energy savings potential, although it is growing with the rising cost of energy and the introduction of ENERGY STAR qualified products.

Industry Recommendations

Research and development - One of the most significant unknowns for assessing MEL automation is the uncertainty around MEL usage patterns so that there are automatic power-down devices and systems to low power states in a way that meets user needs. Specific research needs where industry can contribute include:

1. More research by specific equipment type and customer segment to determine user needs and usage patterns;
2. Power management design needs to consider individual devices and the interconnected system;
3. Micro-switches and supporting middleware, firmware, and software that let devices power down unneeded components;
4. Sensors that help the device understand when users are present or want to use the device;
5. Standard network communication protocols that enable effective power management in a networked environment;
6. Power management technologies that support network administrator needs in terms of ease of administration, reliability and security; and,
7. Applications support for power management.
8. DC electric distribution systems to replace individual rectifiers for electronic equipment
9. Continued to investment in improving component efficiency. Implementing component efficiency measures offers significant energy savings potential, even without technology breakthroughs.
10. Research, development and demonstration (RD&D) on refrigeration leading to commercialization of advanced technologies that are not yet in use. Refrigeration represents around 16 percent of all MELs evaluated. Nearly all refrigeration energy savings in supermarkets and up to 80 percent in commercial real estate (CRE) with dedicated refrigeration systems can

be achieved using better controls, improved fan motors, high efficiency compressors, high efficiency lighting, and advanced door technologies.

Combined Heat and Power

Combined Heat and Power (CHP) is the simultaneous production of electrical and thermal energy from a single energy source. This production occurs near the point of use, and both the electric and thermal energy are utilized. The process is more efficient than conventional electric generation, because the thermal energy is not wasted, and electrical transmission losses are eliminated. Net-zero energy buildings can benefit from CHP technology by producing on-site electricity, heating, and cooling much more efficiently, and by generating renewable energy when biofuels, biomass, or solar energy as used as source fuels. CHP also provides back-up electric generation during power outages and reduces loading on the transmission grid, resulting in a more resilient power system.

There are numerous applications of CHP that can occur over several scales, such as large-scale industrial plant CHP with grid-exchanged power, medium-scale campus CHP with district energy and local micro-grids, and small-scale building-level CHP where the thermal and electric energy are consumed on-site. Because the application range is broad, and the field of potential issues is large, this section will focus primarily on small-scale building-level CHP applications. Medium-scale campus CHP and district energy is discussed further in the Multi-Building Systems section.

Barriers

Small-scale CHP Equipment

Small-scale CHP technologies are still emerging in the marketplace. They are often viewed as being overly-complex for commercial building applications, and cause concern with regard to reliability, first-cost, operational needs, and increased maintenance costs. There is a lack of mature, field-tested, off-the-shelf design solutions that can be readily applied to commercial buildings.

Load Balancing

CHP systems are most economical when all of the generated electrical and thermal energy can be utilized and not wasted – as much of the time as possible. This is difficult to achieve, as the need for electrical and thermal energy varies dramatically in buildings by time-of-day, week, or year. To artificially achieve this load balance, CHP systems are typically sized to satisfy the smaller of the two energy demands. For commercial building applications, this is usually the thermal energy demand resulting from hot water needs. As a result, commercial building CHP systems are usually undersized to meet the full electrical demand, and are cost effective only at buildings with large year-round hot water loads. These restrictions limit the field of cost-effective commercial building CHP applications.

These restrictions could be loosened if there were additional uses for the waste thermal energy (such as conversion to cooling energy), or, if either the electrical or thermal energy could be effectively stored to shift it from times of over-production to times of higher demand. Single-building CHP solutions are in particular need of these technologies, as the various loads of multiple buildings cannot be aggregated to achieve an ideal load balance.

Analysis Tools and Techniques

Conceptually speaking, CHP equipment and design techniques exist in a “no-man’s land” somewhere between supply-side utility technologies, industrial technologies, and building-level systems. As a result, CHP systems are not part of the traditional building design process, and are rarely considered even for advanced building design such as net-zero energy. The thermal and electrical load profile analysis is not a familiar design calculation, and powerful CHP analysis tools are not integrated into existing building energy modeling programs. Furthermore, the use of site energy analysis to evaluate CHP options, versus source energy analysis, is often employed and typically portrays CHP as less effective.

Fossil Fuel Source Energy

CHP systems improve energy efficiency, but have historically relied on fossil fuels for source energy. Environmental permitting issues are frequently an issue for building-level CHP applications, as the on-site combustion of fuels increases site energy consumption – even though there is a net reduction in overall source energy. Also, the cost of the source energy must remain well below that of grid-supplied electricity (the "spark spread"), or CHP applications are not cost effective. Cost-effective renewable source fuels (in particular, non-combustible sources) for small-scale CHP applications are not available, but would contribute enormously toward wide-spread net-zero energy technology adoption.

Existing Buildings Solutions

It can often be difficult to retrofit existing buildings to CHP applications, as the existing electrical and thermal systems are not easily reconfigured, or interior space constraints limit the addition of new equipment. There is not yet a mature track record of attractive building types that can readily and cost-effectively adapt to CHP retrofit and operational needs.

Industry Recommendations

To advance CHP and overcome barriers, industry stakeholders should:

1. Identify opportunities to conduct research, development, and demonstration for small-scale commercial CHP and align with existing state, regional, and national efforts. Develop technological solutions to expand the field of commercial building types available to CHP applications.
2. Expand existing efforts to improve the reliability, maintainability, emissions, and energy conversion efficiency of small-scale generation technologies such as microturbines and fuel cells to improve generation technology.
3. Enhance research and development efforts into thermally activated energy conversion technologies (TATs) to improve the utilization of waste thermal energy for heating, cooling, humidity control, thermal storage, mechanical power, and electrical power.
4. Create new research and development initiatives for small-scale electrical and thermal energy storage systems for building-level CHP applications.
5. Expand the development and demonstration of small-scale modular CHP systems for commercial applications through system integration, size reduction, and building controls integration as a way to package CHP solutions. Increase the number of field tests, demonstrations, and informative case studies.
6. Research and development for renewable CHP source fuels is essential to enabling wide-spread net-zero energy deployment. Emerging renewable energy sources include biofuels, biomass, and concentrating solar technologies. Utilizing these new energy sources requires testing and modification of typical CHP generation technologies to avoid degradation of reliability, maintainability, emissions, and energy performance. It also requires investigation into new fuel gathering, handling, treatment, and storage technologies.
7. Improve CHP analysis, design tools, and techniques. Develop a robust stand-alone public sector (e.g., state and local) analysis program to evaluate a wide range of CHP generation technologies under various building scenarios. Integrate the analysis platform algorithms into existing industry energy modeling tools. Improve education and outreach to building design

professionals for small-scale CHP technologies, including applications, analysis methods, site-versus-source energy, case studies, product information, and cost data.

Multi-Building Systems

The concept of multi-building systems as they relate to net-zero energy buildings is very broad, and this working group explored a variety of topics such as shared building control systems, continuous commissioning systems, virtual distributed energy and controls networks, enterprise reporting, and utility and regulatory structures. This section will focus primarily on topics related to groups of nearby buildings, such as communities, campuses, or districts that are connected via electrical or thermal energy systems.

Optimizing the net-zero energy attributes of groups of buildings over individual buildings has some inherent advantages. For example, it is typically assumed that the renewable energy required by net-zero energy buildings is produced by photovoltaic panels located on individual rooftops. This approach favors the development of low-density low-rise buildings with large roof areas. A more sustainable high-density approach could be achieved through multi-building systems that share renewable energy production resources, such as centralized biomass heating plants. Centralized renewable energy systems at the community, campus, or district scale could be sited where most advantageous, without requiring individual buildings to develop separate small-scale solutions. This approach is key to making net-zero energy more feasible and desirable in high-density urban settings, where individual net-zero buildings may be difficult to achieve due to high floor space to roof area ratio or objectionable in terms of encouraging low-density sprawl.

Examples of multi-building energy systems are shared thermal distribution loops for heating, cooling, or heat pumps; centralized heating and cooling plants; centralized combined heat and power plants (cogeneration); centralized combined heat, power, and cooling plants (trigeneration); district heat pump systems; and shared information systems for building energy management.

Additional advantages of multi-building systems for net-zero energy buildings include the following:

- Source fuel diversity, including renewable sources – in centralized systems, the source energy fuels used to produce electricity, heating, and cooling can be switched more readily than individual building systems. This allows energy sources to change with availability, market conditions, and the need for renewable energy supply.
- Load aggregation – when the thermal and electric needs of multiple buildings are summed, there are often complementary attributes such as the flattening of electric profiles and the distribution and sharing of excess thermal energy. Net-zero energy buildings can benefit enormously from the well-designed collection, distribution, and utilization of waste heat among multiple buildings.
- Shared energy management – it is more economical to install energy management systems in multi-building systems versus individual building systems. This improves performance and energy efficiency.
- Centralized equipment maintenance – it's less expensive to service larger equipment located in a centralized area, versus numerous smaller distributed systems. Central systems typically receive better and more frequent maintenance, improving energy efficiency.
- Larger centralized equipment – multi-building equipment is usually larger, higher-quality and more reliable. Larger equipment is often more energy-efficient.

- Peak thermal load diversity – the coincident peak heating or cooling load of multiple buildings together is less than the sum of all the individual building peak loads. Therefore, the total installed capacity of the shared heating and cooling systems is smaller, and often costs less.
- Resilience and shared equipment redundancy – in centralized systems, electricity, heating, and cooling is typically produced by multiple generation units (e.g., generators, chillers, boilers). If one should fail, there are more available to carry the load. Individual building systems usually rely on single units, and have no capacity for back-up in the event of equipment failure.

Barriers

The majority of barriers to multi-building systems tend to involve societal, economic, or private ownership issues. Technology barriers are somewhat secondary, although there is still ample room for innovation.

Multiple Building Development

Generally speaking, buildings are designed and constructed individually. Outside of zoning law requirements, there is little regard for the attributes, needs, or beneficial resources of nearby buildings. Developing buildings individually is suboptimal, and there is lost opportunity for beneficial shared resources and economies of scale. If groups of buildings were planned and designed on a larger scale, the energy solutions would be likely be more effective than developing individual buildings.

Multiple Ownerships

It is difficult and complicated to share energy systems across multiple buildings with multiple owners. Physical systems have to be installed on private property, legal contracts have to be agreed upon, and complex energy flows must be measured and assigned value. Managing multiple ownerships is complex, and yet aggregating thermal and electrical loads over multiple buildings leads to more optimal systems. At present, the greatest promise for multi-building energy systems lies with single-owner campuses.

Obscurity

Multi-building systems tend to “slip through the cracks” in the societal sense. There is a fairly limited application and history of these systems in the U.S., particularly with regard to commercial buildings. Multi-building solutions tend to get lost between the divisions of building research, and hence are studied less than individual buildings solutions. Multi-building solutions are frequently absent from energy advocacy efforts, utility and public benefits programs, and green building rating systems. Traditional building design processes often do not consider multi-building energy solutions, and lack powerful and flexible analysis tools to evaluate their potential within an integrated design process.

Existing Building Challenges

Applying multi-building systems to existing buildings can be difficult. It is usually not economical to connect existing buildings to multi-building systems until the individual building systems are at the end of their useful life. This moment of opportunity occurs every 10 to 20 years. Individual building owners must be convinced of the benefits of retrofit, and must believe in the long-term economic viability of the entity owning and operating the multi-building system. Creating a new multi-building system is capital intensive, involves considerable business risk, and must occur at sites where there is a high energy demand density. When new systems are established within existing neighborhoods there can be conflicts over site emissions, fuel delivery, and aesthetics. Installing underground distribution systems in existing urban environments is challenging, as traffic disruption and damage to existing underground utilities must be minimized.

The Need for New Technologies

Some multi-building systems, such as district steam, have changed little in over a century. These particular systems matured many years ago, and there is a need to develop new technologies. In particular, the ability to gather, distribute, and utilized waste heat is of particular importance to net-zero energy buildings. Most buildings contain many sources of excess heat that are rejected to the atmosphere, rather than being re-used or converted into other forms of useful energy. The energy entering a building needs to be squeezed for every drop of useful work before it is rejected. Promising systems to assist with that process are water-source heat pump loops, geothermal heat pump loops, energy recovery systems, thermal dehumidification, novel energy cycles, and others.

Industry Recommendations

1. Consider a coordinated state, regional, and national multi-building energy systems program. Currently, efforts are often directed toward single building solutions, and multi-building issues are generally overlooked. Such a coordinated effort would serve to enhance research, development, demonstration, and education efforts that specifically focus on multi-building technology and policy development.

2. Assess the potential for municipal and community-based shared energy systems. Gather models of existing community-based energy systems from state and local jurisdictions. Evaluate shared challenges such as siting issues, emissions requirements, fuel delivery, distribution system right-of-way, metering, and customer needs. Delineate barriers to the development of municipal, neighborhood, and private-sector small-scale energy systems. Investigate approaches to the effective integration of existing buildings into multi-building systems.

3. Research optimal aggregations of building types for shared energy systems. Develop optimal groupings of buildings that aggregate ideal thermal and electrical load shapes. Determine what building types are complementary to sharing waste heat or flattening electric demand profiles, and what type of communities these buildings would create. Evaluate the effect of climate, and new building developments versus existing buildings. Assess the potential energy and economic savings. Determine methods for designing new developments that would allow for future adaptation to multi-building systems.

4. Enhance existing research and development in alternate thermal recovery, distribution, and utilization technologies. Determine common sources and uses for thermal energy recovery and exchange (with or without power generation) at the building and multi-building levels. Develop recovery devices that can be applied to the energy harvesting of all sources of waste thermal energy in a building. Develop energy conversion devices that can effectively utilize the waste thermal energy in new and innovative ways. Research and improve approaches to district geothermal heat pump systems.

5. Determine the potential for active and passive energy storage. Explore approaches for the application of active and passive energy storage, both thermal and electrical, at the building and

multi-building levels. Evaluate technology options, energy savings potential, and the feasibility of shared daily and seasonal storage systems.

6. Determine the potential for shared renewable energy resources. Investigate the challenges to integrating on-site and grid-connected wind, solar, geothermal, and biomass resources at the building and multi-building levels. Evaluate complementary building types, renewable energy sources, and distribution systems. Assess the advantages of multi-building renewable energy systems over single-building renewable systems.

Grid Integration

Market conditions will reward the building or multi-building system able to balance its energy use within its site. Load shaping and load management will be used to mitigate risk. Controllable temporal shifts in energy purchases will be as important as energy efficiency. Anything that can buffer between energy acquisition and energy use will become more valuable and integrating grid-connected intermittent energy sources such as photovoltaics and wind turbines will become increasingly important. Storage technologies of all kinds will be necessarily important. The net zero energy building will be responsible for a growing amount of their power supply. Site-based generation will find greater value through intra-site load shifting.

Smart Grid and Demand Response Technologies

The key to the Smart Grid is to fully and dynamically integrate customers, their loads, and information about their usage into the operation of the grid. Thus, demand response[16] is one of the primary components of the smart grid. The technologies that enable demand response, such as smart meters, active monitoring, communication and control systems, storage systems and other demand control technologies, are foundational to this grid.

Initial efforts in building technology improvement can be directed toward development of tools, strategies, frameworks and pilot projects compatible with the smart grid. In parallel, the implementation of demand response and load shedding strategies over integrated building management systems should be undertaken. The advanced metering, communications, and control technologies of a "smart grid" could allow system operators to optimize the delivery of electricity to their customers both accurately and efficiently. These technologies give customers and utilities detailed feedback that can be used for tracking and managing energy use.

Barriers

While the smart grid is often seen as a technological advance, its efficiency will depend on how customers respond to it. Commercial customers generally are not willing to cede control of equipment and building systems to an external energy services company[17]. Smart grid technology will not necessarily save energy unless utilities base their rate design, education, and programs on research and evaluation.

Today's tariffs discourage participation in demand response in some jurisdictions. Tariffs and market rules were defined assuming once-per-month meter readings. This means that they often do not align well with the peaks and troughs of electricity supply. Flat and block tariffs minimize the risk of non-participation. Traditional tariffs have limited participation in responsive markets. Without wide participation, demand response programs fail.

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[16] Demand response refers to a way to manage peak electricity demand by providing incentives and price signals to utility customers reduce their load during a time of peak demand.

[17] ASHRAE. November 1, 2010. *RE: Smart Grid RFI: Addressing Policy and Logistical Challenges.* Atlanta, GA.

Communication Standards - Without national standards for grid-to-building communication, the cost of building grid-ready building systems is too great for manufacturers. With clear standards for such communication, building owners can automate building responses to market signals.

Micro-Grid Interoperation – Open Automated Demand Response (ADR) - Today's demand-response is a hodge-podge of vendor-specific communications and integrations. While the wider grid could use OASIS[18] Energy Interoperation standard to operate energy markets, and a multi-building system chooses to use Energy Interoperation for its internal market operations, another similarly-sized multi-building system could choose to manage its micro-grid using the developing intra-building energy management specifications. These standards are focused on detailed load management between peers and share more intimate information about business process and energy demands.

Policy - Market forces and state policies have been crucial in enabling the deployment of new demand response and smart grid technologies, but have not been sufficient.

Industry Recommendations

1. Smart grid design should be based on behavioral research as well as technological advances and that utilities match their technologies to the needs of their customers. Encourage thorough testing and evaluation of how customers respond to implementation of various smart grid technologies and services.

2. *Communication Standards* – National interoperability standards developed and endorsed by industry for grid-to-building communication are needed to jump-start building systems that are grid-aware. Two way communications would enable negotiations between the building and the grid and provide adequate pricing signals. The market will reward the building owner who understands energy use in his building, and given the availability of response mechanisms, this will in turn encourage involvement in technology innovations.

3. *Micro-Grid Interoperation – Open ADR* **-** The California Energy Commission (CEC) and Lawrence Berkeley National Laboratory (LBNL) have developed a specification OpenADR which has drawn considerable interest. It is a priority to develop standards for the market interactions between electricity supplier and consumer. This work is underway in the OASIS Energy Interoperation Technical Committee. The CEC and LBL have contributed OpenADR to the Energy Interoperation effort.

   Energy Interoperation will include OpenADR as a standard profile re-factored to sit on the longer-term market interactions for transactional energy. A number of utilities and energy marketers have committed to using the OpenADR standard when it arrives.

4. *Research Needs* – Actively research balancing integrated load, generation, and thermal storage with response to a local price signal and toward stable grid operation.[19]

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[18] Organization for the Advancement of Structured Information Standards, www.oasis-open.org

[19] ASHRAE. November 1, 2010. *RE: Smart Grid RFI: Addressing Policy and Logistical Challenges.* Atlanta, GA.

5. *Research and Demonstration* – Industry research and demonstration projects are needed that document the economic benefits of changing customer behavior to speed adoption of both technology and practices.[20]

6. *Policy* - National policy is needed for demand response and smart grid technologies to proliferate and unlock the potential of renewable energy, demand response, and energy efficiency resources available. Through federal guidance and support, demand response and the smart grid can develop in a more cost-effective and holistic fashion, greatly accelerating and increasing the benefits that would be achieved by individual state actions.

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[20] Ibid.

Energy Modeling Tools

Building energy modeling is the detailed computer simulation of energy consumption within a building. It is used to estimate building energy consumption under various scenarios, often with the intent to optimize building energy efficiency. Energy modeling simulates the whole-building interaction among building systems and the local climate, solar loading, and occupant schedules. The energy trade-offs between various design approaches can then be quantified, and the model is used a decision tool for evaluating design decisions. Energy models are a powerful support tool for the integrated design process and net zero energy design efforts.

Energy models of existing buildings can also be developed. These models are often calibrated for greater accuracy using measured energy consumption data. Calibrated existing building energy models are especially useful for estimating the interactive energy savings among multiple energy retrofits. Because field measurements and demonstrations are expensive and time consuming, simulations will play key role in studying energy, economic, environmental impact of integrated building systems.

Increasingly, the ability to demonstrate compliance with codes or program requirements such as California's Savings by Design program and to access incentives such as the federal tax deduction for energy-efficient commercial buildings relies on energy modeling. All of the working groups recognized the need for easier yet more sophisticated simulation and design tools as a critical area to increase the use of new technologies, understand increasingly complex system integrations and interactions, and enable an integrated design process.

Barriers

Modeling Tools and the Design Process

The use of energy models to make tradeoffs between building systems is integral to realizing the greatest energy savings at the most reasonable cost. Unfortunately, the complexity and cost of applying modeling tools limits or prevents their use. Energy modeling is rarely applied in the early design phase when potential energy savings benefits are at their greatest. Many tools are complex, time-intensive and require high degrees of expertise and thus are limited to large building projects where the costs of energy simulations are not a huge part of the total budget.

Often energy modeling is used to document the estimated performance of a completed design, rather than as a decision-making tool to improve energy performance. Sometimes, energy consumption estimates do not compare well with actual energy consumption following construction.

Modeling Tool Practitioners

Energy modeling is difficult. It involves a host of subtle and complex systems issues that defy complete capture by computer algorithms. Improved modeling tools can alleviate a portion of this difficulty, but skilled human intervention is required for the foreseeable future. Energy modeling requires knowledge of thermal science, building physics, the building design process, and inter-disciplinary knowledge of the various building systems. Energy modeling also requires experience with the unpublished quirks and shortcomings of energy modeling software tools – knowledge that can only be gained through hard experience. With the exception of a few scattered academic programs and some helpful list-serves, energy modeling is typically learned informally on-the-job, often in isolation. No wide-spread educational approach has been developed. Recent increases in the demand for energy modeling services have not been met by the market, resulting in a shortage of skilled practitioners.

Modeling Tool Capabilities

Existing building energy tools are complex, cumbersome, and limited in capabilities. There is uneven progress in the ability to model advanced envelope, lighting, daylighting, HVAC, and passive energy systems that are the cornerstones of net-zero energy designs. For instance, many existing tools provide illuminance levels, but not luminance levels and daylight quality metrics. Glare is particularly difficult to define and measure, and multiple view points are needed which significantly increase the light vectors that must be analyzed and simulated.

At the same time, existing tools are often too powerful to act as agile scoping tools during the critical early design phase. Modeling tools must achieve a balance between the divergent goals of becoming faster and easier to use, and becoming powerful enough to address innovative and complex systems. Most tools are developed to assist the new building design process, and few possess features to support the modeling of existing buildings.

Industry Recommendations

1. *Formalize energy modeler training and education resources.* Work in collaboration with professional societies, universities, and education providers to improve available education and training resources for energy modelers. Formalize the body of knowledge required to be an energy modeler. Support certification programs to improve professional credibility (e.g., ASHRAE Building Energy Modeling Professional program).

2. *Simplify access to and support the long-term integration of energy modeling tools with Building Information Modeling (BIM) technology.* The promise of BIM technology allows for the integrated linkage of a virtual building information model to energy modeling software. This linkage could significantly reduce energy modeling effort and cost, while improving model quality and allowing for integrated design inputs through a shared information repository. Through BIM, energy modeling could be performed more often during the critical early design phase. However, significant challenges remain in improving BIM interoperability, improving data interpretation, and developing a rich and reliable BIM data set that satisfies energy modeling needs. Reliable and wide-scale energy modeling benefits of BIM integration may lie 10 to 15 years in the future.

3. *Improve the effectiveness of modeling tools during early design stages.* Develop a modeling tool with an early design user interface that allows for the rapid evaluation of conceptual approaches using minimal amounts of input data. The tool should be capable of evaluating energy scenarios during pre-design charrettes or during early design team meetings. It should be fast enough to produce results in real-time while participants are actively vetting design approaches. Easy-to-use tools to enable high-speed evaluation of envelope integrity/condition; semi-automated techniques; lighting system design; etc. are likely essential to make this cost-effective and dramatically reduce the labor intensity required. Simple modeling programs with technology plug-ins that are accurate and low-cost to operate need to be developed.

4. *Define needed improvements to enhance the usability of existing modeling tools.* Industry practitioners should define and push for changes that improve both analysis power and model development speed. Some possible improvements for industry practitioners to consider include utilizing a two-level energy model development approach, where a powerful academic and research modeling platform is maintained as a test-bed for a production-oriented modeling tool that can keep pace with the design process.

   Other improvements should include a state-of-the-art multiple-level graphical user interface that provides access to all underlying analysis capabilities; improved program execution speed; automated model baseline generation for common energy codes, standards, and performance rating methods; a utility to assist in the creation, comparison, and evaluation of energy-savings design approaches; development of intelligent default data; and automated quality control for model input and output.

   Finally, develop peak load analysis tools, including specific user interfaces and reporting tools. The peak load analysis performed by design engineers to size HVAC equipment contains much of the base information needed for a building energy model. This enhancement would reduce modeling cost and encourage modeling during early design.

5. *Improve and expand the technologies available for modeling tool analysis.* Expand efforts to research and develop advanced open-source algorithms for energy modeling tools. Improve analyses for advanced active systems such as daylighting controls, radiant heating and cooling, dedicated outdoor air systems, underfloor air distribution, centralized and distributed geothermal heat pump systems, complex heat recovery loops, low-temperature heating, and other similar advanced systems. Develop improved analysis approaches for passive systems such as natural ventilation, daylighting, and advanced building envelopes. Develop enhanced modeling methods for occupant behavior, miscellaneous loads, combined heat and power, multi-building systems, and renewable energy technologies.

6. *Develop a comprehensive simulation tool that can perform the complete life-cycle impact assessment*. Such a tool should be able to perform life-cycle assessments by system (e.g. lighting controls, HVAC, etc.) but also include the broader, holistic impact of a particular system on other building systems.

7. *Develop modeling tools that specifically support the energy simulation of existing buildings.* Advanced tools that are accurate and easy to run are required to optimize the operation of the each building system over the whole building load profile. Develop automated tools that assist in the calibration of existing building energy models through input of measured energy data - including monthly utility data, short-term energy monitoring, and spot measurements.

8. *Improve the accuracy of modeling tools through the empirical validation of energy model algorithms and techniques.* Support research comparing modeled energy consumption estimates to empirical data from both individual building components and whole-building energy consumption. Determine the sources of discrepancies and alleviate through improved modeling algorithms and modeling techniques.

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