Zero Net Energy Building Controls: Characteristics, Impacts and Lessons

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ABSTRACT

Controls – Controls – Controls! This aspect of commercial buildings has been frequently cited as the linchpin to creating, and maintaining, buildings that perform for comfort and for optimum energy use. This report summarizes the key findings and recommendations from the commercial building research into Zero Net Energy[1] (ZNE) building controls conducted by New Buildings Institute (NBI) in 2015. The research examined the perspectives on controls from design firms, operators, and occupants of several different ZNE buildings. A full report of the project is freely available.

Control systems can deliver important benefits that support the owner and occupants as well as goals of reduced energy use in buildings. This research found that while controls are considered highly critical to energy performance, there are often installation, communication and integration issues. Controls integration across multiple systems is increasing and operators now need greater knowledge and skills in programming, computerized networking and controls. With the increasing role of controls, the controls contractor needs to become a first-tier part of projects. As the trend of low cost interconnectivity continues, the real estate ownership, management and energy efficiency industries have a collective need to harness a landslide of control evolution and occupant expectations toward buildings that operate elegantly, efficiently and in an environmentally sound manner. It is our hope that this study provides some stepping stones for effective controls in the next generation of ZNE buildings.

Introduction

Design firms, owners, operators and occupants are all familiar with the term “green building”, although they may define it differently. The green building trend has accelerated the expectation and adoption of energy efficient technologies. A new leader in energy efficient buildings has emerged – Zero Net Energy – which has captured the attention and engagement of practitioners in design, construction, real estate, and policy. The first cited non-residential building attempting to get to net zero in the U.S. was built over 15 years ago as a demonstration effort at Oberlin University (Johnson 2012).

Today the ZNE model has moved beyond demonstration buildings and now commercial buildings of every type, size, and climate zone are striving to Get to Zero. The largest study of ZNE buildings in North America – NBI’s Getting to Zero Status Update – has been conducted three times in the past decade documenting the growth and trends of ZNE buildings (NBI 2014).

ZNE buildings rely on building and system-level controls, monitoring, energy management, and operator/tenant feedback to help meet their performance goals. These

[1] ZNE buildings have greatly reduced energy loads such that, over a year, 100% of the building’s annual energy use can be met with onsite renewable energy. Also called Net Zero Energy or Zero Energy buildings. Buildings without renewable energy but with equivalent low-energy use may be termed Ultra Low Energy. The US Department of Energy has published a common definition of Net Zero Buildings (DOE 2015).

buildings are at the forefront of energy efficient design and operations, yet little was known regarding energy-related control systems in these advanced structures.

Key Objectives. The three key objectives were:

1. The Design, Selection and the System. What control systems did the designers choose and why? What were the selection criteria, method, and the actual attributes of the control system installed at a set of ZNE buildings? What lessons can they share to increase good design integration and performance outcomes of controls?
2. The Energy Impact. What energy performance levels are these ZNE buildings able to target and obtain? Can we identify savings attributed to various control systems or within the whole building energy use? How important were the control systems in achieving the buildings energy target?
3. The Use and User Experience. How are controls being operated, what is effective, and what is lacking? What are the perspectives and experience of the operators and occupants? What is needed for best outcomes in performance? What are the most desired and applied functions? What training/experience is needed to operate the controls?

Methodology

The research approach was based on utilization of existing lists of ZNE buildings in the NBI Getting to Zero buildings database (NBI 2015a) and the findings in the 2014 NBI report "Getting to Zero Status Update" (NBI 2014). These represent the most comprehensive list of ZNE buildings in North America and include varying degrees of information on the building characteristics, technologies, energy use, and owner perspectives on ZNE. For this controls study, the research team worked with a steering committee to identify priority building types and review areas of inquiry. The surveys were conducted in person, via phone and/or online. The research team identified an initial target list of over 60 projects and design teams and performed extensive outreach to engage representatives of the 23 ZNE buildings that made up the final building sample.

Surveys and Interviews

The fundamental data gathering mechanism used in this project was to conduct one-on-one phone and in-person interviews using previously prepared survey questions. These questions included yes/no, ranking, multiple choice questions, and narrative response. Many questions were narrative response and all questions allowed comments.

The surveys were targeted to parties responsible for the selection, operation and utilization of the control systems. The research sample included design firms (architect and engineering), of the 23 buildings, operator surveys of six buildings, and 130 occupant surveys representing seven buildings.

The survey instrument included over 100 customized questions for the design teams and operators. Designer and operator interviews typically lasted over an hour and covered topics including building and control system characteristics, energy impacts, lessons learned, industry trends and recommendations. The online occupant survey had ten questions; responses were anonymous. This survey focused on the occupants' experience and preferences around controls.

Findings

Getting to Zero is strongly facilitated by the leadership, experience and technical design knowledge of firms that have worked on numerous low and zero energy buildings. The research set of 23 buildings reflect leading practitioners in both architecture and engineering, as well as owners that support or mandate a low-energy building. During the conceptual and pre-design stage, the fundamental program for the building is established, which, in the case of these buildings, included aggressively-low energy use outcomes. These firms knew these outcomes were feasible, not fantasy, and 100% of the participants considered setting early energy targets as key to the design process and outcomes.

While some buildings have actual metered data of their Energy Use Intensity (EUI) others are based on their targets as shown in Figure 1. The energy use (NBI collected both modelled and metered energy data from participants) of these buildings collectively is an average EUI of just 22 kBtu/sf/yr. This is 75% less than the US national average of 93 kBtu/sf/yr (CBECS 2003).

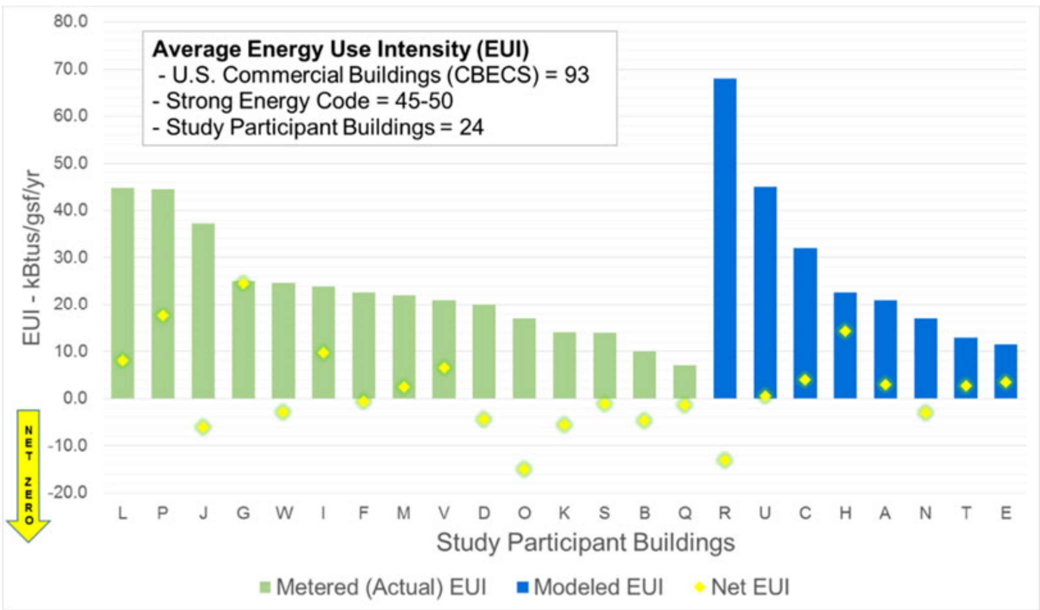

Figure 1. Energy Use Intensity (EUI) of Participant Buildings

The Buildings and People

The research team and steering committee selected offices, higher/general education, libraries, courthouses, and public assembly buildings over 10,000 square feet (although a limited number of smaller buildings were included in the sample) as the target building types as well as number of retrofit projects. This building type selection was due to the transferability of findings in these sectors to a wide range of buildings.

The design firm participants have extensive experience in the two primary building types (office and higher education) and have worked on an average of four ZNE buildings. An initial finding was that these designers set energy related targets (Figure 2) and maintain ongoing tracking and feedback on post-occupancy energy use and operations.

Building ID	Zero Net Energy	LEED Certified	Living Building Challenge	Zero Net Electric	Carbon Neutral	Architecture 2030 Compliant	Zero Net Energy Ready
A	■						
B	■		■				
D	■	■					
E				■			
F	■	■	■		■		
G							■
H	■	■					
I	■						
J	■						
K	■	■		■	■		
L	■	■			■		
M	■	■				■	
N	■		■			■	
O	■	■	■				
P	■			■			
R	■	■		■	■	■	
S	■		■	■			
T	■	■	■				
U		■		■			
V	■						
W	■						

Figure 2. Energy Goals Set by Projects

Control Design Selection Process

Early identification and communication of energy goals was critical to the design and selection process of the controls featured in the buildings covered by this survey. All respondents identified setting energy targets as very important or critical to the design process and outcomes.

Given the importance of the controls systems to the performance goals of these buildings and the importance of getting the key players involved in the design process as early as possible, a majority of the design teams (78%) rated prior experience with the vendor's system as the top criterion when it comes to selecting a controls vendor. The fact that this criterion was selected more frequently than cost demonstrates the critical role of the design team's working relationship with the vendor or their system.

The engineer of record (EOR) was responsible for the control design and selection process and the hub through which key decisions were made; they also typically filled the role of mechanical engineer. It was these people who interfaced with the owner and pulled the subcontractors into the process as needed. The EOR was also responsible for writing the control specifications and most importantly the sequence of operations for the controls systems. The architect was involved in the selection process of the controls for only 12 of the 23 projects.

In 39% of the buildings, the early design and selection process for controls included the building operator. However, when asked who ideally should be involved in this early design and selection process, the majority of design teams that had excluded the building operator from this process indicated that the building operator should have been involved. This sentiment was echoed by the six building operators that were surveyed for this project.

Control Systems and Integration

A primary goal of this project was to characterize the controls technology and strategies used in ZNE buildings. Also of note was the degree to which the different end uses were controlled in an integrated fashion. Figure 3 shows the extent of system level controls integration for the 21 buildings for which this information was available.

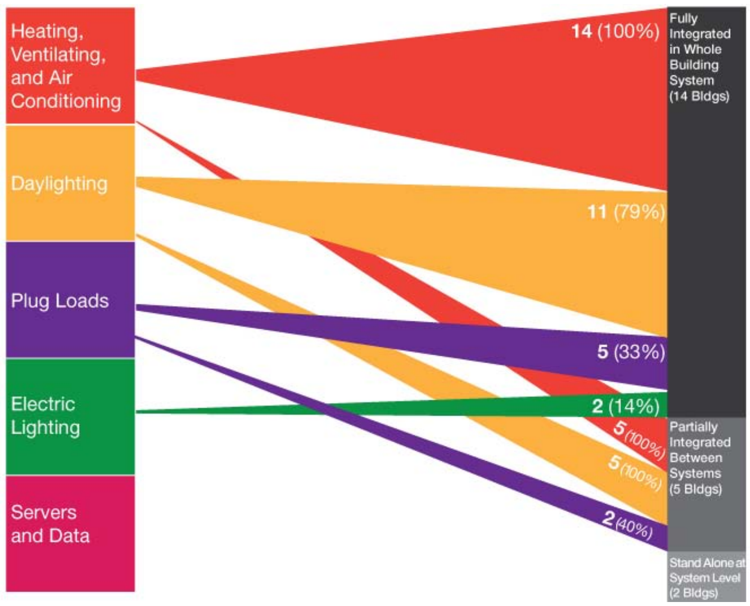

Figure 3. Extent of Controls Integration by End-Use

At the whole building level, the overwhelming majority (91%) of buildings surveyed use controls systems that integrate multiple end-uses. Most (67%) employ a fully integrated controls architecture that can address all controlled end-uses in a centralized and automated fashion. Some (24%) have controls systems that are partially integrated between end-uses. Only a few (9%) have no whole-building controls architecture with controls only at the end-use level. These buildings tend to be smaller and use simpler design approaches. However, it should be noted that despite the preponderance of integrated controls, the controls sequences are not fully responsible for driving performance: 74% of the buildings surveyed rely on the occupant for some part of the success of the controls operations. The highest-performing buildings have engaged operators and occupants standing on the shoulders of intelligent and integrated controls systems.

HVAC Systems and Controls

Utilizing efficient HVAC systems with sophisticated automated control sequences is only part of the equation. An equally vital part of Getting to Zero is to utilize behavioral control strategies, especially when multiple system types (e.g. mechanical and natural ventilation) are present in the same building. Most buildings surveyed used an active system as their primary source of heating and cooling. Nine buildings, or 39% of those surveyed, used passive heating and cooling as the primary means of providing space conditioning. Some buildings use multiple strategies, for example, passive heating with backup provided by air source heat pumps. It is also evident that heat pumps, fairly evenly divided between ground source and air source, are the most prominent type of HVAC system in these high performing buildings (17 of 23 buildings use a heat pump of some kind).

An additional part of the survey addressed the HVAC distribution system and demonstrates another unique aspect of ZNE buildings: the designers are not fans of fan energy loads due to the high energy demand of moving air through duct work and noise. Within this dataset, 64% of the buildings used radiant systems (52% used radiant heating; 35% used radiant cooling) to meet thermal comfort needs coupled with a Dedicated Outdoor Air System (DOAS) to address ventilation needs.

Natural ventilation is a very common strategy in ZNE buildings and among high-performance buildings in general. Many buildings used multiple innovative ventilation strategies simultaneously. For example, some buildings used natural ventilation during the day (in some cases with mechanized windows or large-scale integrated systems, in other cases relying on occupants to operate windows manually) and used automated night flush ventilation to reduce thermal loads. A quarter of buildings surveyed employed heat recovery or thermal storage tanks.

Half of the buildings (12 of 23) allow the occupants to exert direct control over the HVAC system. In most cases this means either opening and closing windows or temporarily overriding the thermostat settings. In most cases where occupants may override HVAC set points, there is a limit to how far the override can go, either by duration or by temperature deviation.

The great majority of the buildings (71%) rely to some extent on behavioral strategies for managing thermal comfort. These strategies include, to a greater or lesser extent, empowering and engaging occupants to adjust their personal environment and their own attire as needed for thermal comfort. In some cases this simply means wearing short sleeves in summer and a sweater in winter.

Lighting Control Strategies

The observed controls of electric lights include everything from wall switches to centralized scheduled lighting with occupancy sensors and manual overrides. Most design teams noted that for lighting specifically, it is important to allow occupants to interact with the controls system; the most common method was by simple wall switches (78% of buildings). Occupancy sensors are also quite common and are used in half of the buildings surveyed. In several cases, the lights are designed so that the default setting is “off” and occupants must turn on the lights. This approach has obvious energy advantages over the more traditional systems that come on by default and must be turned off manually. Dimming fixtures are also an important component of these buildings, allowing the building to take advantage of natural light and conditions requiring less light. Continuous dimming was used in 60% of the buildings, stepped dimming was used in 35% of buildings, and only one building reported not using any dimming controls whatsoever.

The majority of buildings used wired controls for their electric lighting. However, 29% of buildings reported used some wireless controls. Luminaire-level lighting controls – which are controllable at each luminaire rather than in zones of light fixtures, while lightly represented in this sample (10% of buildings) are an up-and-coming design element in high performance buildings.

Daylighting is a critical component in allowing ZNE buildings to reach their design goals, applied in all but two buildings. Photocells and occupancy sensors were used, in combination or isolation, in every building surveyed. Most buildings (74%) used some form of exterior shading; half (52%) used some form of interior shading and 34% of those were automated or a combination of automated and manual. In several cases the project was unable to add either exterior or interior shading due to spatial, historic, or other design constraints.

Plug Load Controls

Plug loads are an increasingly important factor in overall building energy use. In some ZNE buildings plug loads can account for more than 50% of total energy use (NREL 2012). However, plug loads are often considered a tenant matter and are outside of the responsibility of the design team. Yet the majority of buildings surveyed (64%) use some kind of plug load controls or monitoring due to the need to have all building loads accounted for and monitored toward ZNE goals. Of these buildings, the plug load control strategies employed vary from centralized to localized.

Building Operators

All of the building operators surveyed agreed that someone in their position should be brought into the design process as early as possible, and should be involved in all sequence development efforts as well as the commissioning process (only one in six of the respondents on these buildings was involved at the design phase). Not only will this facilitate a smoother start-up process, but will also allow the operator to understand the design intent behind the key strategies and systems. As noted by one of the operators, they are the ones "who have to understand how to use the systems every day and have to ultimately buy into owning the system."

The operators also noted that their relationship with the control vendor is essential to ensuring that the building is operated in an optimal manner. This relationship involves frequent communication, especially in the first year of operation when the operator and vendor have to work as a team to troubleshoot problems and implement solutions. In several cases, a control integrator contributed significantly to this process.

While training was mentioned as being important, there was not a consistent approach to formal training, nor was there a common professional development path that led them to their current position. Most of the training was characterized as happening on-the-job informally, with a heavy reliance on the Operations and Maintenance (O&M) Manual and the Commissioning process and report. Most of the operators surveyed had taken it upon themselves to compile a System Support or Procedure Manual to ensure the persistence of efficient operations.

Building Occupants

As greater focus is placed on the role of occupants in the energy outcomes of buildings, it is increasingly important for design teams to consider their interactions with the building and its control systems. These buildings had generally very high levels of occupant satisfaction, regardless of control access, with the lighting and the daylighting (70% and 75% respectively), the indoor air quality and heating (63% and 57% respectively), and plug load controls (45%); cooling had a lower portion of satisfied occupants (only 26%). Generally, the occupants felt satisfied with the electric lighting controls featured in these buildings where 65% are 'neutral' or 'about right'. The findings also point to an important call for greater controllability in regards to shading and glare with 38% wanting 'somewhat more' or 'more control' shading and glare controllability. For ZNE buildings, perhaps more so than standard buildings, a flaw in design or control can adversely impact the public perception of these leading buildings. While some owners were hesitant to survey occupants, either due to interruption of their primary work or to avoid soliciting feedback that might be negative and/or warrant action and investment, others recognized that learning of and resolving problems has great benefits.

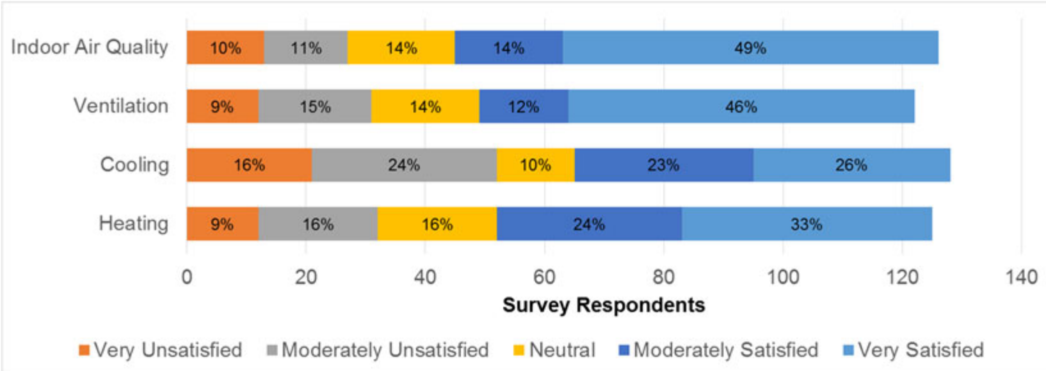

Figure 4: Occupant Satisfaction with HVAC Systems and Characteristics

Conclusions: Controls at the Nexus of Performance

As the built environment continues to move toward lower energy use, controls become a more critical and nuanced aspect of achieving and maintaining energy and operational expectations. There is a renewed focus on passive design strategies as a foundation for getting to low and zero net energy buildings, while at the same time the world of abundant sensors, wireless technology and automation is accelerating. In parallel, policy makers and utilities are looking to buildings to reduce carbon emissions from power generation and to shift to other models of energy production and distribution by 2030. The nexus of these market, policy and technology factors occurs in zero net energy buildings, where the interplay of design, technology, control, operations, and occupants affect the end performance.

The 23 leading edge buildings in this study applied a range of strategies and technologies sharing a common intent to minimize energy use and Get to Zero. Their design teams also share many common perspectives on the value and role of controls. Every project design firm selected both controls and early energy targets as very important or critical to getting to ZNE. They also universally agreed that every single project "has some controls problems." The reasons were not focused on any specific product, but rather on the process to 'get it right' and installation issues. While some suggested simplifying things and avoiding as much automation and points of failure as possible, the majority said system integration, extensive metering, automation, granular levels of data and feedback are here to stay and are beneficial to the process.

Solutions in New Roles and Old Relationships

From both the design team and the operators' perspective, the solutions lie in an increased need for the controls contractor and the building operator to be more actively engaged with the design early, during commissioning and after occupancy. A more robust scope for the controls contractor that includes responsibility for extensive commissioning, sequence documentation, and longer term availability post-occupancy may seem like a pipe-dream during budget development, but there are losses in real money and confidence in controls lost without this extended role. Since prior experience with the controls system is the top basis for their selecting a vendor (86%), even over price (57%), both the design firm and vendor are vested in creating a successful relationship and outcome.

In the current process, operators often run the building through a series of trial and errors with no formal training. They cite control and/or equipment component failure as the main reason for ongoing call backs with the design team – another costly factor for both parties – while the majority of respondents found most issues associated with poor installation, lack of commissioning, and improper settings. These are matters that could be reduced or resolved with more connection between design, controls and operator pre- and post-occupancy. In these ways, ZNE buildings mirror all buildings – getting system sequences and controls commissioned correctly can be the Achilles heel of building performance. But ZNE buildings have high performance systems and onsite renewables, and often tend toward greater system integration, metering, monitoring and feedback as standard practice. Therefore, research participants in both new construction and retrofit projects identified a new role that some called “Controls Integrator” while others noted a “ZNE Commissioning Agent.” Both titles identify an emerging role for a multi-system and controls expert that has continuity with regard to the building performance outcomes for both energy use and production, from design through to occupancy.

Zero Net Energy Driven by Good Design, High Performance Systems and Shading

These buildings are designed to, and in many cases documented at, energy use levels 50% less than most new buildings today and 75% less than average existing buildings, with renewables to offset the reduced loads. Getting to Zero is an integrated approach that begins with applying a good site orientation, envelope design and passive strategies to reduce energy needs, followed by the mechanical systems and their controls to drive the next layer of savings[2]. The HVAC systems in these buildings tend toward high performance with radiant heating and cooling, ground and air source heat pumps and variable refrigeration flow systems. Ventilation is usually provided through manual and automated windows (natural ventilation) and/or dedicated outside air systems. Lighting is almost always integrated with both daylight design strategies and controls, resulting in lighting power densities that are 40-60% less than a code building.

Reducing occupant-driven plug load energy remains a challenge, but most projects incorporated some control technologies such as smart power strips, outlet level controls or centralized power management, and all buildings incorporated energy-use dashboards and occupant feedback. The majority of design firms attributed HVAC, lighting and plugs each with having a greater than 15% impact on the energy savings: overall energy goal success hinges on successful control of these systems. Interior shades and blinds are an old ally for controlling glare and heat, but they are having some renaissance with new designs and automation beyond simply a draw cord used (or not) by the occupant. Most projects included interior shading with manual and/or automated controls driven by thermal energy and occupant comfort benefits.

[2] Exterior shading, and in one case electro-chromatic glass, as a part of the envelope design, were credited in the energy section questions as being a major strategy toward reducing the mechanical cooling system size.

Occupants are a New Operator

The role of occupants on energy outcomes has never been greater. Designers and operators see increasing value and importance in both system- and building-level controls (even as system efficiencies increase), but occupant impact remains a wildcard. In three quarters of the buildings surveyed, occupant interaction is part of the control strategy, from roles with operable windows and blinds to plug load controls and energy awareness campaigns. But occupants must not be left to their own devices completely. The study found a strong participant message to allow engagement with building systems combined with “Design for Off™” through a hybrid of manual and automated controls where systems return to a default triggered by time or sensor and messaging[3]. Yet nearly 70% of the occupant respondents said they do not receive any communications on the topic of their role in reducing energy consumption in their building, further indicating a gap from design intent to operations and occupancy. Occupants, according to one design firm, are the best building ‘sensors’ and we need their perspective to tune the building controls. Both the design teams and the occupants recognized that in today’s buildings with extensive plug loads and changing work and occupancy patterns the occupant is now an operator.

Game Changers Include Integration, Engagement and a New Utility World

The survey included an open ended question on emerging or game-changing trends for building controls. The results are grouped around three main themes, with a few outliers. First, the area of **Integrated and Low Cost Control Systems** was widely referenced as the major change currently in process and seen as on a trajectory of increased adoption. This included integrating more end-uses, greater wired and wireless connectivity between sensors and controls, greater data available from a single system sensor (e.g., light levels, occupancy and temperature), network interties and automation of the control management. Protocol standardization was cited as a trend that supports this area of change. Smart buildings leverage technology to lower the costs of and achieve business and energy goals. This is changing the way building controls are designed, installed and managed, and that creates both risks and significant opportunities.

Also notable were the responses regarding **adaptive controls** that learn and respond (adapt) to occupant-based needs and preferences. The residential thermostat “Nest” was cited as an example, but the use of ‘artificial intelligence’ in commercial buildings was described as a key missing piece. Adaptive controls were also mentioned with the integration of external real time weather sensors that help predict the needed settings that day or hour in response to climate conditions.

The second group of trends focused on **Occupant and Operator Engagement** through more extensive monitoring and feedback. Universal adoption of energy dashboards in these buildings was a first step, but participants noted trends for more graphical and intuitive user interfaces with key performance indicators, simpler monitoring accessible for smaller buildings and retrofits, and fault detection and diagnostics (FDD) embedded in equipment at the manufacturer. Occupant cues to open/close windows, turn off receptacle-based equipment, and relate energy use to higher values and goals based on dashboards, computer programs, smart phone apps, wearable technology (e.g., smart watches) or other visual messaging were also forms of engagement and trends.

[3] “Design for Off” was developed and trademarked by Ecotope and referenced by several projects in this survey.

Changes in the world of **Utility Programs and Pricing** was cited by a few respondents as a game-changer. Demand response programs with price signals for time of use or reductions at peak can alter the controls strategy. Most of these buildings now have bi-directional transactions (buying and selling) of energy with the utility company. The growth of variable and intermittent distributed generation at the building scale is creating new load curves for utilities and spurring reassessments of their base infrastructure and commodity pricing. Since energy costs are a key factor in the analysis of getting to zero, utility decisions can impact building-scale decisions.

Lastly, a set of trends were seen as noteworthy that overlap with the three groups but are worth noting individually. They are technologies growing in part due to ZNE targets: a) **direct current** (DC) building systems, b) **onsite energy storage** and c) **robotics**.

Industry Implications and Recommendations

When looking at the conclusions of this study, the findings need to be parsed by control-type and audience. The new world of integrated sensors, metering, monitoring and controls is not simple, nor are the system manufacturers, designers, builders, operators, owners or occupants. Add in the energy industry and policy and political dispositions, and you have a matrix of factors and entities looking to find a blend of financial prosperity and environmental stewardship. The implications lie in the reader's interests, but some clear messages apply across industries.

The increasing complexity of controls means a new learning curve and new players with controls expertise. The attention on energy efficiency of buildings as a carbon-reduction strategy is only going to increase from the few to the many, and the impacts will spread from components to construction, from program to performance requirements. This ZNE world is not a disconnected world, standing alone with its solar panels and wall packs of batteries – it is a community of buildings and leaders interacting within a new web of energy exchange. That these current buildings have demonstrated that ZNE is real, and that it brings benefits beyond energy, will only accelerate the need for innovative controls from the widget to the whole building.

Recommendations

Industry should move beyond products to performance-based services and find ways to help transition a much larger-scale set of knowledge, skills and application of strategies and technologies to get all buildings to low and zero net energy. This report scratches the surface of the fast-moving industry of control integration in high performance buildings. Greater investigation of bridging the design to operations gap, the training issues and new roles for control contractors and operators, occupant interest and impact of controls engagement, and the trade-offs of simplicity versus increased data and feedback are all called out from this research. There are five clear areas that repeat through the research that serve as recommendations to help move the current trend of controls integration toward a much greater likelihood of increased and ongoing energy performance and user satisfaction. These are:

1. **Prioritize Passive Strategies.** Prioritize passive strategies first during design then layer in controls to optimize the whole building outcomes.
2. **Integrate the Controls Contractor.** The controls contractor needs to be a primary team member from design through occupancy.
3. **Increase Operator Training and Support.** Bring controls training and improved hand-off documentation to the operators and provide ongoing connectivity with the design team and controls contractor.

4. **Occupants are Operators but Default Settings Need to be the Backup.** Provide occupants with energy use engagement and control access with a ‘hybrid’ system that returns controls to default settings and “Off”.
5. **Build Industry Awareness and Knowledge of Emerging Trends**. Increase industry awareness and knowledge of a) integrated, wireless and adaptive controls, b) user feedback and dashboards, c) DC systems and renewable integration, d) utility load management, price and program issues, and e) policy drivers toward low and zero net energy buildings through outreach, education, marketing, workshops, industry publications and programs.

Addressing these recommendations through the chain of building and controls manufacturing, design, and operations, and influencing programs and policies, will help smooth the path to performance. As the trend of low cost interconnectivity continues, the real estate ownership, management and energy efficiency industries have a collective need to harness a landslide of control evolution and occupant expectations toward buildings that operate elegantly and efficiently with low environmental impact. Based on advances in design and operations of this elite class of ultra-high performance ZNE buildings, and the attention the buildings sector is getting from entrepreneur and tech startups, we anticipate the pace of change in the controls industry will accelerate even more rapidly in the coming decade. It is our hope that this study provides some stepping stones for effective controls in the next generation of ZNE buildings.

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