# ZERO NET ENERGY BUILDING CONTROLS

## Characteristics, Energy Impacts and Lessons


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### OVERVIEW

New Buildings Institute (NBI) conducted this research on controls in Zero Net Energy (ZNE) commercial buildings from December 2014 to September 2015, with a final webinar presentation in November 2015. ZNE buildings have greatly reduced energy loads such that, over a year, 100 percent of the building's annual energy use can be met with onsite renewable energy. ZNE buildings are an emerging trend in response to energy efficiency and carbon reduction policies, as well as market interest in 'green and sustainable' environments. NBI's last decade of work in both building performance outcomes and ZNE buildings identified a gap of information concerning the control systems applied in these leading edge buildings. The outcomes of this collaborative research project help fill that gap and enable a better understanding for CABA, its members and the building and energy industry. The findings can help: manufacturers target improvements; design teams better integrate controls and work with contractors more effectively; and utilities identify program priorities leading to a next generation of buildings that can be on the path to zero.

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The Steering Committee contributed their time and industry expertise to the project at numerous Web conference meetings and through interim and final review of the surveys and this extensive report. The organizations and their representatives are:

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The research was conducted by New Buildings Institute with contributions from our research partners. Their direct experience with some of the buildings, relationships with designers and owners, expertise on ZNE and, foremost, their persistence and willingness to dig into this topic with attitudes of both interest and enjoyment made this project a pleasure and of value.

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## TABLE OF CONTENTS

## FIGURES

## TABLES

# EXECUTIVE SUMMARY

This Executive Summary is for the commercial building research project: CABA Zero Net Energy Buildings *Controls: Characteristics, Energy Impacts and Lessons*, conducted by New Buildings Institute (NBI) and led by the Continental Association of Buildings Automation (CABA) and published in November 2015.[1] This research examined the controls perspectives from design firms responsible for 23 buildings, operators of six buildings and occupants of seven buildings.

The approach in this summary is to distill the project and information down, yet maintain the high-level and critical aspects of the findings. For easy cross reference, the nine major sections in this executive summary contained here are aligned with the full report's Chapters 1-9.

Control systems can deliver important benefits that support the owner and occupants as well as the goals of reduced energy use in buildings. We hope these results will spur continued attention and ongoing improvement and evolution of building and system-level controls. NBI and CABA welcome input and inquiry regarding the findings of this study, as well as references to other leading resources, buildings or firms. The work of getting to zero energy for the majority of buildings in North America is a long road, and your distribution of this report and contribution to ongoing efforts are important and appreciated.

## EXECUTIVE SUMMARY INTRODUCTION

### About This Report

The Continental Automated Buildings Association (CABA) commissioned New Buildings Institute (NBI) to conduct research on controls in Zero Net Energy commercial buildings. ZNE buildings are an emerging trend in response to energy efficiency and carbon reduction policies, as well as market interest in 'green and sustainable' environments. NBI's last decade of work in building performance outcomes and ZNE buildings identified a gap in information concerning the control systems applied in these leading edge buildings. The outcomes of this collaborative research project can help fill that gap and enable a better understanding for CABA, its members, and the building and energy industry. The findings can help: manufacturers target improvements; design teams better integrate controls and work with contractors more effectively; and utilities identify program priorities leading to a next generation of buildings on the path to zero. The research was conducted from December 2014 to September 2015 with a final webinar presentation in November 2015.

### Role of the Steering Committee

The Steering Committee represents a cross-section of providers in the energy and building controls marketplace. Representatives from each organization joined NBI and CABA on regular collaboration calls to guide the research scope and ensure it met project objectives. Figure 1 shows the 18 companies and organizations that were on the Steering Committee and supported this project.

1. ZNE buildings have greatly reduced energy loads such that, over a year, 100 percent of the building's annual energy use can be met with onsite renewable energy. Also called Net Zero Energy or Zero Energy buildings.

Figure 1: Project Steering Committee and Funders

## About CABA

The Continental Automated Buildings Association (CABA) is an international not-for-profit industry association, founded in 1988, dedicated to the advancement of connected home and building technologies. The organization is supported by an international membership of over 325 organizations involved in the design, manufacture, installation and retailing of products relating to home automation and building automation. Public organizations, including utilities and government are also members. CABA's mandate includes providing its members with networking and market research opportunities. CABA also encourages the development of industry standards and protocols, and leads cross-industry initiatives.

Please visit http://www.caba.org for more information.

## About NBI

New Buildings Institute (NBI) is a non-profit organization working to improve the energy performance of commercial buildings. As a technical resource for governments, utilities, energy efficiency advocates and the building industry, NBI acts as a carrier of ideas between these groups and works collaboratively to put the best innovations for advanced buildings into action. Our primary work areas are focused on creating the thought leadership that defines "What's Next" in our industry, assessing effectiveness of emerging technologies, promoting best practice design approaches and helping to guide policies and programs that will significantly improve the energy efficiency of commercial buildings.

## The Research Team

New Buildings Institute had several research partners that supported the project and were essential to parts of the research results. Figure 2 shows the six entities that had partnership roles in this study.

Figure 2: Research Team

## INTRODUCTION

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. The building and system-level controls can be a cornerstone that secures performance, or a weak link that creates challenges for design teams and operators. ZNE buildings are now at the forefront of energy efficient design and operations, yet little is known regarding energy-related control systems in these advanced structures. This project focused on the control aspects in ZNE buildings.

### Key Objectives

The objective was to characterize monitoring and control systems in zero net energy buildings focused on three key areas from the designer and user experience. The research outcomes will be widely published and used to influence controls design, installation, operations and occupant engagement.

**Three key objectives:**

1) **The Design, Selection and the System**. What did they 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 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 to low energy targets were various systems in these buildings?
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 Database* and the findings in the 2014 *Getting to Zero Status Update* (ZNE Update).[2,3] 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. The research team and Steering Committee identified the priority building types and reviewed the areas of inquiry for the surveys. The surveys were conducted in person, via phone and/or through an online link. The research team identified an initial target list of over 60 projects and design teams and did extensive outreach to get the research target of 20+ building projects.

**Surveys**: Survey questions included yes/no, ranking, multiple choice, with the ability to select more than one response in some cases, and narrative response. Many questions were narrative response and all questions allowed comments. The research was targeted to parties responsible for the selection, operation and utilization of the control systems. The research sample included design firms (architect and engineering), design team surveys of 23 buildings, operator surveys of six buildings, and occupant surveys from seven buildings. The survey instrument included over 100 customized questions for the design teams and operators broken into the following topics:

A. About You
B. Takeaways and Lessons Learned
C. Building Information
D. Energy Performance
E. Control System Description and Characteristics
F. Design Process
G. Control Selection Process
H. Building Handoff and Post Occupancy

2. The Getting to Zero Database is a publicly available resource with information and case studies on ZNE buildings. http://newbuildings.org/getting-to-zero-database.
3. http://newbuildings.org//2014-zne-update

The occupant survey had 10 questions, and responses were anonymous. It focused on the awareness of the occupant of energy targets, their engagement and experience with control systems, and their desire for greater or less ability to control energy using features.

## ES 1. GETTING TO ZERO

This study on commercial building controls is in the context of ZNE buildings, so defining ZNE and the trends are helpful to understanding the building projects and the findings.

### Defining ZNE

The terms used to determine if a building is ZNE are as follows:[4]

- **Zero Net Energy (ZNE) Buildings** – ZNE buildings have greatly reduced energy loads such that, over a year, 100 percent of the building's annual energy use can be met with onsite renewable energy.
- **Zero** – This means 'nothing' – plain and simple.
- **Net** – A result from combining more than one item. In this case from energy used in the building and energy produced in the building. If the energy used by the building is completely (or more) replaced by energy produced by renewable sources at the building and/or building site, then the building's energy use is 'net' zero. Remember, energy use and production are constantly changing so the 'net' varies widely over the year. For this reason 'net' is calculated as an average over 12 months.
- **Energy** – Energy means all energy (electric, gas, steam, liquid fuel, etc.) consumed at the building interior and exterior (typically lights metered with the building, such as entry lights, walkways, signage, etc.). [5]
- **Energy Use Intensity (EUI)** – In order to normalize the various fuels in a building, all the energy forms for both use and production/generation are converted to thousands (k) of British Thermal Units (Btu) and then divided by the square feet (sf) of the building with 'yr' representing the 12 month period of data. The EUI is expressed as kBtu/sf/yr and is the most commonly used metric of a building's energy use or performance. It also allows benchmarking and comparisons of buildings. Here is the equation and an example for a ZNE building:

Figure 3: Equation and Example Calculation for Zero Net Energy


(A) 12 months of Building Energy Use in kBtu/sf/yr – (B) 12 months of Onsite Renewable Production in kBtu/sf/yr = (C) Annual Net Energy Use Intensity (EUI) in kBtu/sf/yr

This study of controls includes both verified (documented ZNE performance) and emerging (striving for) ZNE buildings.

### ZNE Trends and Policies

The real estate industry has been riding a wave of green building over the past 15-20 years. LEED, Green Globes, or LEED equivalent buildings are now standard practice in many markets and required by policy in others.[6] 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 largest study of ZNE buildings in North America - *The 2014 Getting to Zero Status Update* (ZNE Update) – has been conducted by NBI three times over the past 10

4. See the full report Glossary for additional definitions.
5. The inclusion of parking lot lighting or other larger outdoor energy use varies by project since it is often separately metered.
6. The U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED).

years, documenting this growth and the trends of ZNE buildings, with 225 buildings achieving or striving for net zero. Of these 225 buildings, seven are located in Canada. Twenty-three of these buildings are featured in this study.

There are also a growing number of programs, goals, policies and standards that are putting Getting to Zero as the end game to help offset carbon emissions. Examples include, California goals for new state facilities to move to ZNE in 2020-2025, and all new and 50 percent of existing commercial buildings statewide to be ZNE by 2030.[7] Vancouver, British Columbia, has likewise adopted of a policy to be carbon neutral by 2020. Colorado, Massachusetts, Minnesota, New Mexico, Vermont, Washington – as well as many large and small cities across North America – have or are considering similar policies. Although the number of ZNE buildings today remains small as a proportion of overall commercial floor space, it is trending upward as building energy use remains the single greatest contributor to carbon emissions in the U.S.[8] ZNE buildings rely on building and system-level energy controls, monitoring, energy management, and operator/tenant feedback to help meet their low energy use goals.

### Control Trends

The building industry has seen a dramatic rise of connectivity and monitoring that includes energy and equipment performance assessment. This extends well beyond the historical use of whole building monitoring and now includes discrete building systems, individual equipment and even each plug outlet. The boundary for controls is also expanding beyond the building as distributed generation (renewables or other onsite generation), demand response (controlling equipment use through price or demand signals), and onsite storage (renewable generation integrated batteries) become parts of the new bilateral transaction of energy with utilities and other providers of services.

These trends are driven in part by dramatic reduction in the costs of sensors and the rise of wireless and direct digital controls (DDC). This, in turn, is tied to trends from: the Internet of Things (IoT), OEM (original equipment manufacturer) integration of these low cost sensors, the rise of LED technologies, gains in universal communications protocols (e.g., BACnet), fault detection and diagnostics, and the widening use of computers and handheld devices for data access, management, and system control.

An additional, and significant trend is the interest and insistence of people on two contemporary topics: a) individual control and data access and b) the environmental character of their work or retail space. These interests merge in the area of controls where today's most highly desired young-tech work spaces reflect, and advertise, these features. A 'green' work space often includes control for natural ventilation, shading variations, daylight and lighting responsiveness customized at the individual light fixture (rather than a large zone), thermal control or e-communications for feedback regarding comfort, and lobby displays of the building energy and renewable status and awards.

## ES 2. THE BUILDINGS AND PEOPLE

The initial part of the research established the characteristics of the buildings and the survey respondents.

### The Buildings

Research participants were selected based on their role in designing or operating a specific ZNE building.

Table 1 shows the list of buildings for which interviews or surveys were conducted. Within the study results, the building names are anonymized with letters. 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. This building type selection was due to the transferability of findings in these sectors to a wide range of buildings.

7. California Energy Efficiency Strategic Plan http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/eesp/.
8. According to the US Department of Energy, buildings consumed 41 percent of all energy in the US. Architecture 2030 has a good summary of building sector energy use: http://architecture2030.org/buildings_problem_why/.

Table 1: List of Participant ZNE Buildings Buildings and People Summary

| Project | Location | Size Range | Building Type | Retrofit | Operator Survery Completed |
|---|---|---|---|---|---|
| 435 Indio Way | CA | 25k - 50k sf | Office | X | |
| Bullitt Foundation Cascadia Center for Sustainable Design and Construction | WA | 50k - 100k sf | Office | | X |
| Cornell NYC Tech First Academic Building | NY | over 100k sf | Education | | |
| David and Lucile Packard Foundation | CA | 25k - 50k sf | Office | | X |
| DPR Construction San Francisco Office | CA | 10k - 25k sf | Office | X | |
| Exploratorium | CA | over 100k sf | Other | X | |
| Hanover Page Mill Building | CA | 50k - 100k sf | Office | | |
| IDeAs Z2 Office Building | CA | 5k - 10k sf | Office | X | |
| Lane Community College, Downtown Academic Center | OR | 50k - 100k sf | Education | | |
| Leslie Shao-Ming Field Station at Jasper Ridge" | CA | 5k - 10k sf | Education | | |
| Massachusetts Division of Fisheries & Wildlife Field HQ | MA | 25k - 50k sf | Office | | |
| Morphosis Architecture Studio | CA | 10k - 25k sf | Office | | |
| NREL Research Support Facility | CO | over 100k sf | Office | | X |
| Rice Fergus Miller Office & Studio | WA | 25k - 50k sf | Office | X | |
| Rocky Mountain Institute Innovation Center | CO | 10k - 25k sf | Office | | |
| Sacred Heart Schools Stevens Family Library | CA | 5k - 10k sf | Education | | X |
| San Luis National Wildlife Refuge HQ and Visitor Center | CA | 10k - 25k sf | Office | | |
| UC San Diego J Craig Venter Institute | CA | 25k - 50k sf | Other | | |
| UniverCity Childcare Centre | BC | 5k - 10k sf | Education | | |
| VanDusen Botanical Garden Visitor Centre | BC | 10k - 25k sf | Assembly | | X |
| Watsonville Water Resources Center | CA | 10k - 25k sf | Office | | |
| Wayne Aspinall Courthouse & Fed Bldg | CO | 25k - 50k sf | Courthouse | X | |
| West Berkeley Public Library | CA | 5k - 10k sf | Library | | X |

### Buildings and People Summary

The following characterizations apply to the buildings and the research participants:

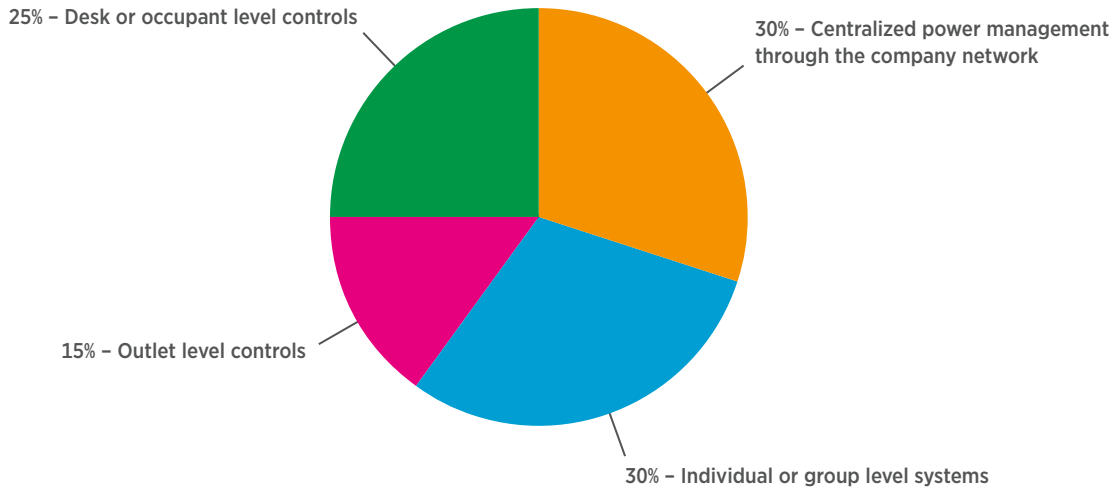
- The buildings studied are all derived from NBI's North America Getting to Zero database and represent buildings striving for ZNE performance.
- The study set of 23 buildings are primarily 10,000 – 100,000+ square feet and composed of offices and higher education buildings. A courthouse, two laboratories, a library and a museum as well as a few buildings of smaller size are also represented.
- Although the majority of buildings in the study are located in California due to the high concentration of ZNE buildings located there, the full set of buildings represents a wide range of climates.
- The individual participants within the design firms have extensive experience in the two primary building types (office and higher education) and with ZNE buildings (an average of four previous buildings each).
- Contrary to standard practice, these designers set energy targets and maintain ongoing tracking and feedback on post-occupancy energy use and operations.

## ES 3. TYPES OF CONTROLS

One of the primary goals of this project was to characterize the controls technology and strategies used in ZNE buildings within the consideration that controls are, of course, dependent on what systems are used in the building.

Plug load controls, a relatively new entry into the building and system-level controls world, was recognized as an energy use factor that is often outside of the hands of the design firm. 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 the centralized to the localized, as shown in Figure 4.

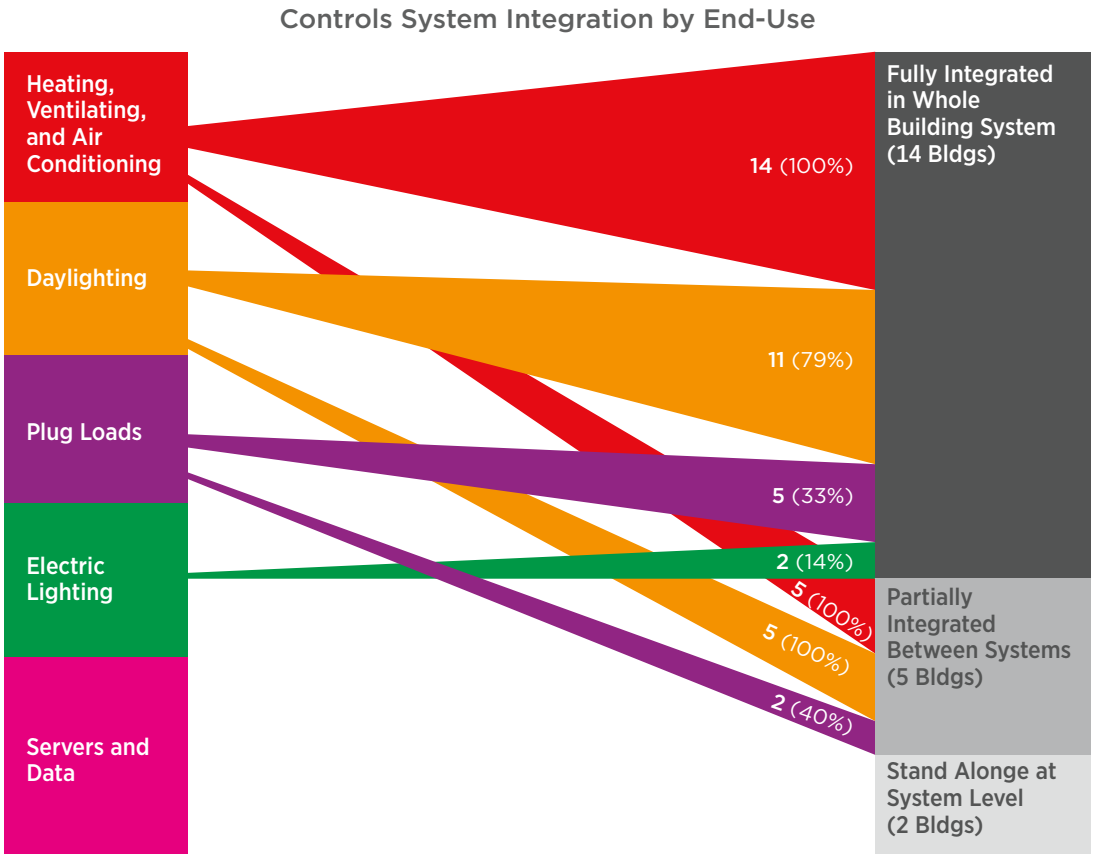
Figure 4: Plug Load Control and Monitoring Strategies



### Summary of the Types of Controls

- All of the participants ranked building control strategies either very important or critical to ensuring a ZNE outcome.
- The vast majority (91%) of the buildings use control systems that integrate multiple end-uses.
- Most (67%) of the buildings have an integrated whole-building control system to address all major 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. Figure 5 shows the extent of system level controls integration.
- Most buildings used a combination of automated and manual controls to adjust the building's environment, e.g., when occupants manually open windows, the HVAC zonal programming is overridden until the window is shut.
- Light switches are still more prevalent than occupancy sensors, but intelligent light switches are becoming more common.
- Some buildings have light switches whose default setting is "off," and are programmed so that that the lights must be manually turned on and then will eventually turn themselves back off.
- Daylighting controls are an integral part of high performance buildings.
- Glare control and shading must be done properly to realize the benefits of daylighting. Most designers used fixed elements (overhangs, louvers) or manual roller shades.
- Interior shades or blinds were used in over half of the projects (52% - 12 projects) toward their energy reduction and occupant comfort goals, and 34 percent of these (four projects) applied automation to the shades or blinds.
- Automated shading was selected to improve thermal controllability and energy savings according to the design teams.
- Managing plug loads is challenging in all buildings; in high performance buildings with highly efficient major systems (HVAC, lighting, etc.), this challenge is more apparent. While 64 percent of the projects included plug load controls, with most using a variety of controls solutions to address plug load energy use, it still remains a tough nut to crack.
- Despite the preponderance of integrated controls, the controls sequences are not everything: fully 74 percent 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.

Figure 5: Extent of End-Use Controls Integration Use




## ES 4. CONTROL DESIGN SELECTION PROCESS

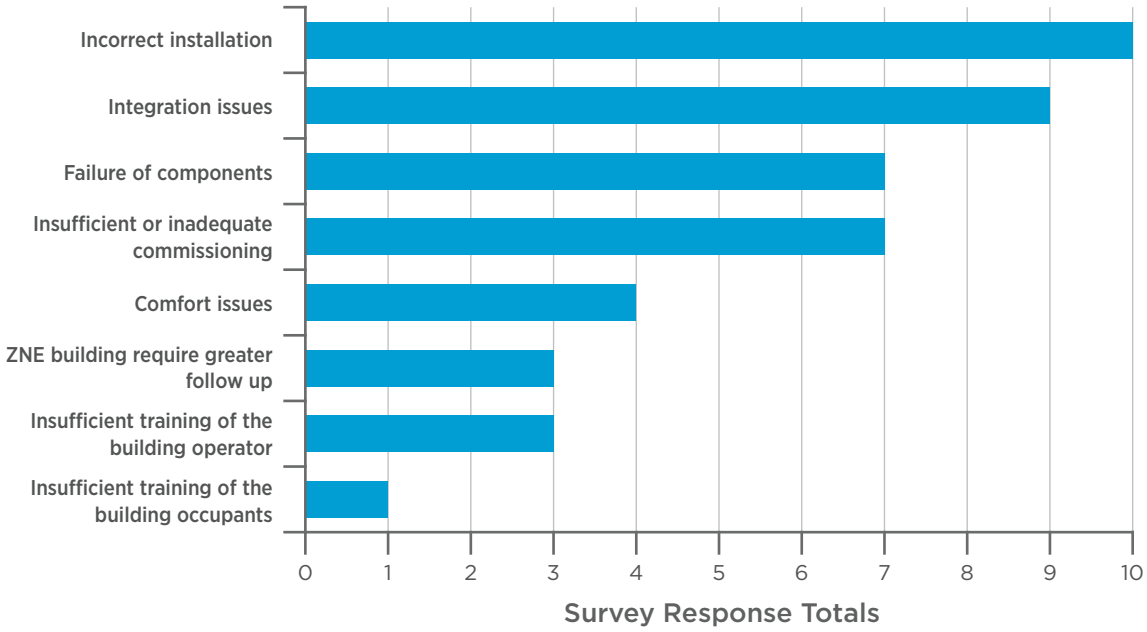
Feedback from this section of the study made it clear that designing a ZNE building involves rigid execution of the design intent, thorough documentation, specifications and detailed sequence of operations, while still allowing for a great deal of built in flexibility when it comes to implementation, and ultimately, building operation. While this survey demonstrated that there are plenty of commonalities in approaches to achieving a ZNE goal, it also demonstrated that how one ultimately implements a ZNE design is built on experience and approaches can vary.

### Control Selection Process Summary

- Early identification and communication of energy goals was critical to the design and selection process of the controls.
- Selection of the controls typically falls to the engineer of record, with some input from the building owner and an assortment of subcontractors.
- A vast majority (86%) selected prior experience with the vendors system is a top criteria, ahead of 57 percent that chose price.
- Most (66%) of respondents say that the attributes of the user interface and preference setting were very important or critical to ensuring proper use by the operator.
- The use of open source versus proprietary communication protocols does not appear to limit the selection process for building controls, nor does the use of open source protocols mitigate integration issues in the field.

- Despite the focus on performance and the qualification of the design and construction teams associated with these projects, incorrect installation of controls systems in the field is the greatest reason for excessive follow-up, followed by integration issues (Figure 6).

Figure 6: Reasons for Greater Follow up by Design Team




## ES 5. USER EXPERIENCE

While we have seen the market for ZNE continue to grow, the building industry still has a long way to go in order to formally acknowledge the role that the building operator plays in determining the success of a project, and in providing them with the tools they need in order to see greater market penetration of ZNE buildings.

### Operations Survey Summary

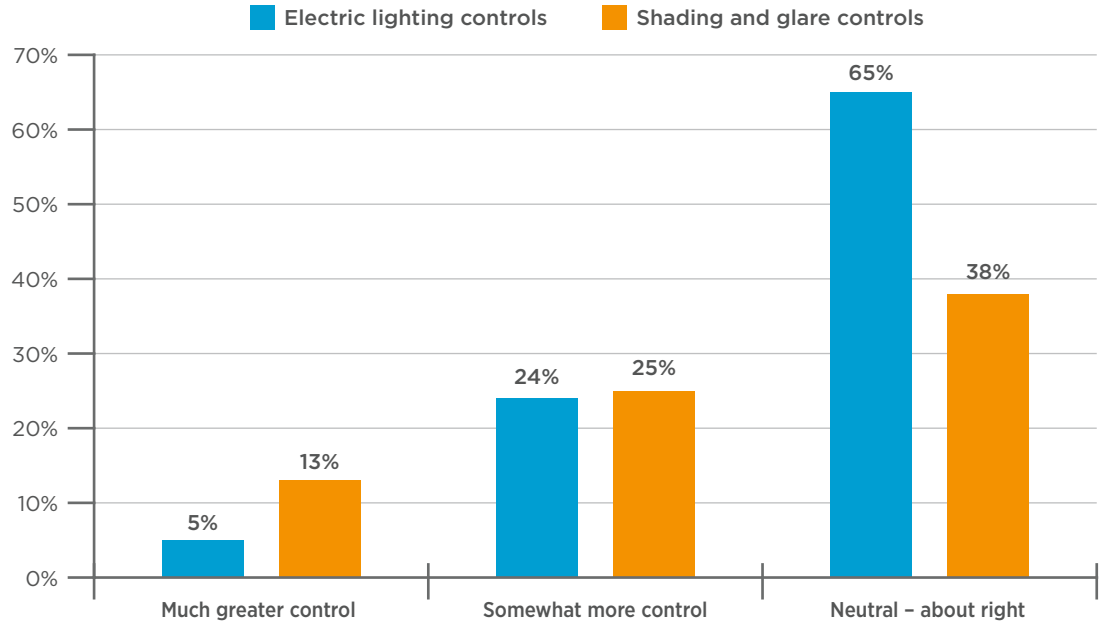
- All of the participants agreed that the building operator should be brought into the design process as early as possible, and should be involved in all sequence development efforts as well as the commissioning process (only one in six of the respondents on these buildings was involved at the design phase). Not only will this facilitate a smoother startup 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 building operator's 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 is important, there was not a consistent approach to formal training that these operators had gone through, nor was there a common professional development path that led them to their current position. Most of the training was characterized as happening informally on-the-ground, with a heavy reliance on the Operations and Maintenance (O&M) Manual and the commissioning process and report.
- The building operator is responsible for compiling a System Support or Procedure Manual, which is important to ensuring the persistence of efficient operations and ensuring that the project is meeting its performance goals.

- Five of the six surveyed agreed that the value of investing in controls for these buildings is increasing. Similarly, four of the six agreed that a building designed with numerous passive systems did not reduce the scope of controls needed to effectively operate the building.

## Occupant Survey Summary

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. For the most part, occupants felt satisfied with the electric lighting controls featured in these buildings where 65 percent are 'neutral' or 'about right'. The findings also point to an important call for greater controllability in regards to shading and glare with 38 percent wanting 'somewhat more' or 'more control' shading and glare controllability (Figure 7).

Figure 7: Occupant Interest in Interaction with Lighting and Shade Controls




Given the energy performance goals of these projects and the feedback provided by the occupants surveyed, it appears that the design teams and building operators have for the most part successfully walked the line between automation and reliance on the building occupants to interact with the systems in providing healthy and comfortable interior environments. Below is the summary of the occupant surveys:

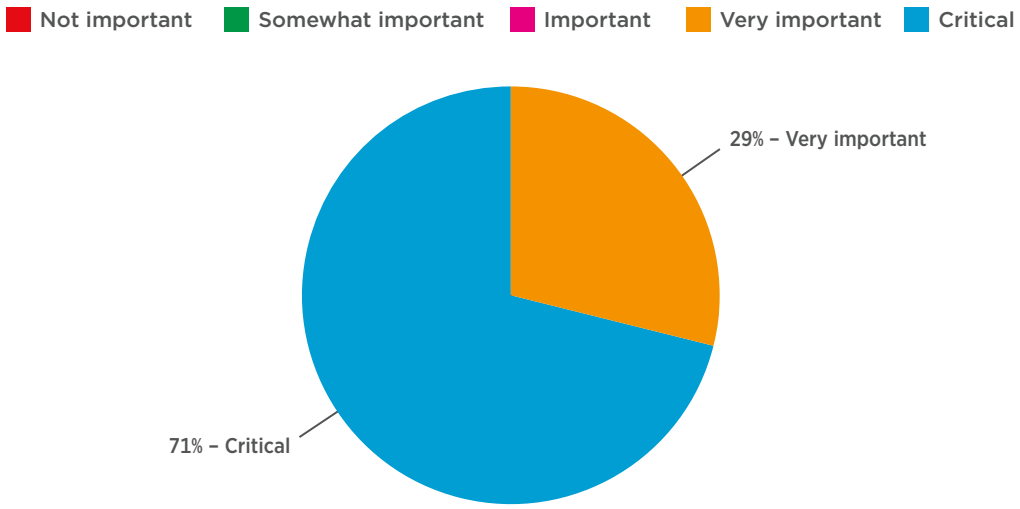
- Occupants are very satisfied with the quality of light in their spaces.
- In providing ample daylighting and views, it is also important to allow occupants to have the ability to control shading elements in response to glare.
- The level of satisfaction with the lighting and daylighting, regardless of control access, was quite high in these buildings, with 70 percent in the moderate to very satisfied category with its characteristics. With regard to daylighting, a noteworthy 75 percent of occupants indicated that they were moderately or very satisfied with the daylighting system and characteristics.
- Occupants responded favorably to the ventilation strategies featured in these buildings, including natural ventilation and dedicated outdoor air systems.
- The heating systems and strategies appeared to be well regarded, while more occupants expressed a desire to more finely control cooling in their zones.

- The plug load controls don't appear to be problematic or obtrusive for most of the building occupants.

## ES 6. ENERGY 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 percent of the participants considered setting early energy targets as key to the design process and outcomes (Figure 8).

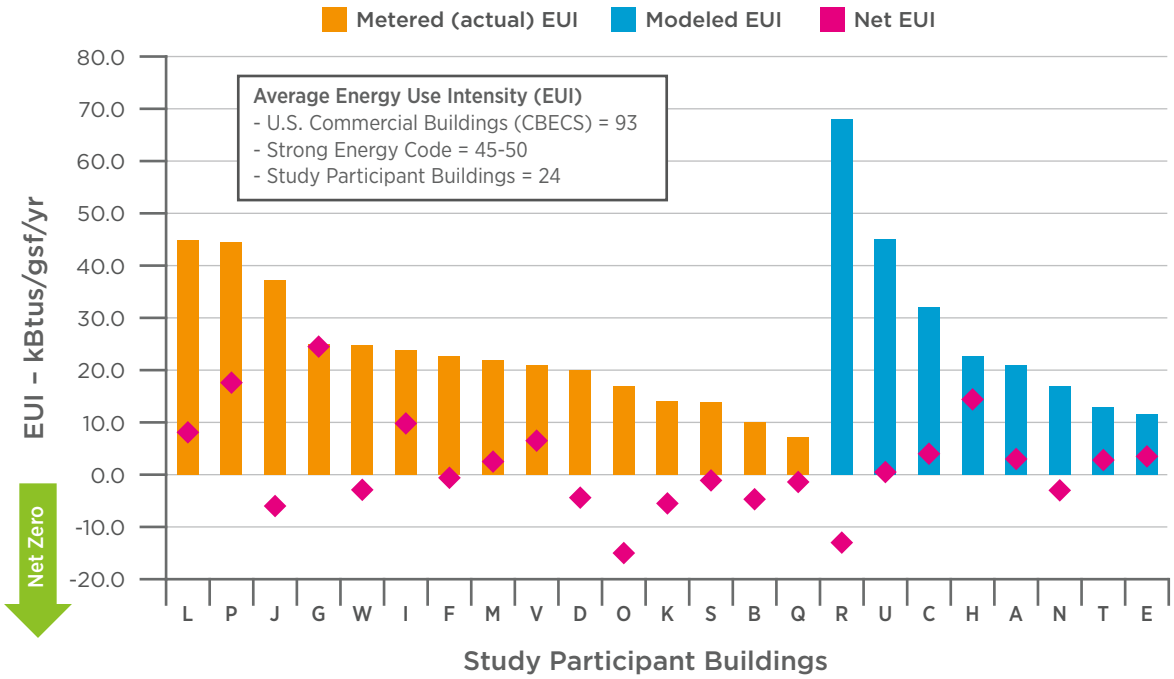
Figure 8: The Value of Setting Early Energy Targets to the Performance Outcome




'Zero' Energy Buildings use energy, but to get to 'net' zero they must have energy use so low that onsite renewables can supply 100 percent or more of the building's energy use over a year, resulting in a net use of zero. A commercial building designed to ZNE typically uses 25 percent or less (75 percent reduction) of a standard existing building of the same type and size, or approximately half that of a building built to strong energy code levels.[9] While some buildings have actual metered data of their Energy Use Intensity (EUI) others are based on their targets as shown in Figure 9.[10] These buildings collectively have targets and outcomes with an average EUI of just 22 kBtu/sf/yr, and that drops to an average EUI of just 19 kBtu/sf/yr when the two lab buildings are not in the average. This level of energy use, when applied more universally across policies and codes, will dramatically change the energy generation and carbon characteristics of the built environment for the better.

9. There is a wide range of energy codes in the U.S. with the strongest energy codes (IECC 2013, IgCC, Title 24 California) resulting in code buildings that are very energy efficient. These codes are also on paths to get to zero energy standards over the next decade.
10. Energy Use Intensity (EUI) is a metric of whole building energy use expressed in kBtu/sf/yr.

Figure 9: Energy Use Intensity (EUI) of Participant Buildings




Overall, finalizing building commissioning, ongoing monitoring and data quality control affect a project's ability to meet targets. It should be noted that not all buildings that target ZNE will reach that outcome, but the design and ongoing effort usually result in exemplary performance. Next, the study drilled into estimates of the system contribution to these low energy outcomes.

## Energy Findings Summary

### Whole Building Energy Aspects

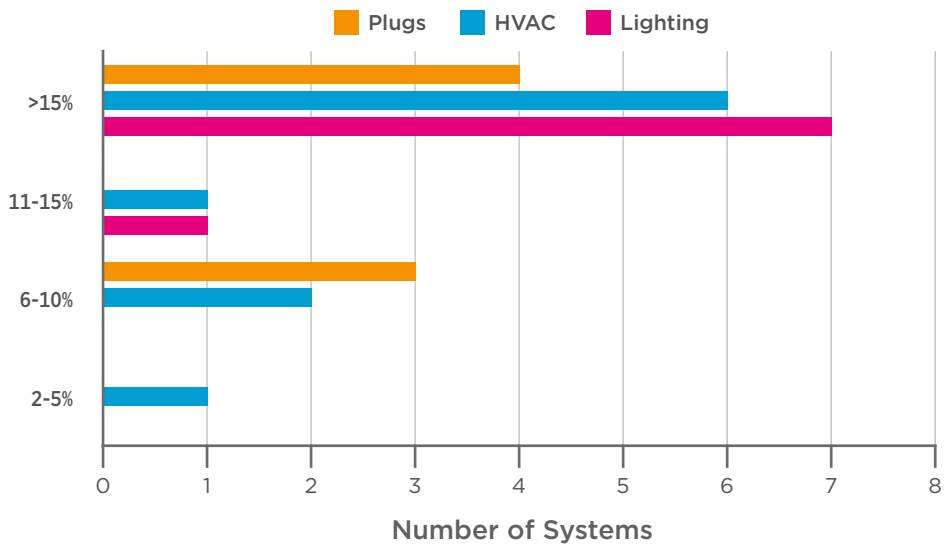
- The projects primarily used a High Performance or a LEED building as the baseline.
- Most firms utilized more than one energy modeling software and noted that for radiant heating/cooling systems and natural ventilation, Integrated Environmental Solutions (IES) and Thermal Analysis Simulation (TAS) software provided improved analysis.
- The energy use (modeled and metered) of these buildings collectively is an average EUI of just 22 kBtu/sf/yr while the US national average is 93 kBtu/sf/yr.
- The buildings' high efficiency HVAC systems - such as ground source and air source heat pumps, radiant heating and cooling distribution and Variable Refrigerant Volume systems – are cited as key, after building siting and envelope design, to the low energy use of these buildings.

### System Energy Aspects

- Lighting and Plug Load projected or metered energy use was well below baselines:
  - > Lighting Power Density (LPD) 40-60 percent less than code.
  - > Plug load targets 60 percent less than standard baselines.
- System-level contribution to the projected whole building energy savings ranged from six percent to greater than 15 percent (Figure 10):
  - > **Lighting Controls**. Selected as > 15% and never less than 11% of the whole building savings, with daylighting controls as the most common reference.

> **HVAC Controls**. Selected as >15% of the whole building savings. HVAC strategies were to apply passive strategies first, with controls for natural ventilation, night flush and thermal set point controls, and then to optimize the mechanical system control and monitoring.
> **Shades or Blinds**. 33% of those with shades or blinds selected that this strategy "Contributed to thermal energy savings in the model sufficient to reduce the HVAC system."
> **Plug Load Controls**. Selected as either >15% or 6-10% of whole building savings.

Figure 10: Whole Building Energy Savings per Controlled System




- The occupant's role in energy savings was considered a key factor to getting low energy outcomes by the majority of participants:
  > All of the projects employed, or plan, the use of a public energy dashboard as one method to try to influence occupants' attention to the building's energy performance.
  > Nearly three-quarters (74%) of the design team projects included occupant direct engagement, with controls including light levels, window operations, thermal settings, and plug load management.
  > The occupant should not be solely responsible for optimizing system settings or remembering to turn them off. Designers usually incorporated a default reset for systems with occupant access to controls, while approximately one-quarter of the projects kept the system controls autonomous.
  > Occupant education and ongoing connection with the building performance and their impacts through such methods as emails, signage, and even gamifying energy use were the most frequently cited non-control strategies.

## ES 7. TEN TAKEAWAYS

At the front end of the survey were a set of 'Takeaways' that captured the participants' ranking and commentary on high-level topics regarding controls. The findings are presented grouped by questions with quantitative responses and commentary response to questions.

### Ten Takeaways Summary

The Ten Takeaways represent a summary of the overall perspective from the participants on high level aspects of building controls in commercial buildings.

**Quantitative Responses**

1. How important are building control strategies to ensure a ZNE outcome?
   - All the participants ranked controls as either very important or critical (33% and 67% respectively).
2. Would you select the same control systems for a similar building today?
   - Over three-quarters of the participants (77%) would select the same controls system for a similar building today.[11]
3. Considering that passive design strategies and improving technology efficiencies are reducing building energy use, is the value of control systems increasing or decreasing?
   - Over three-quarters of the participants (78%) thought that the value of a wider range of controls systems is increasing or majorly increasing, even while building energy use is being reduced from other factors such as passive design and improved technology efficiencies.
4. Please indicate your response to the following statements: *a) Controls are getting easier to design and specify; b) The ability to integrate controls from multiple systems is improving; c) The Internet of Things (IoT) is helping simplify the path to ZNE; d) Control communication platforms and protocols between systems need improvement; and e) Projects always have some control problems.*
   - a - c) Most participants were in the middle ground on whether controls are getting easier to design and specify, if integrating controls was improving and if IoT was simplifying the path to zero, with the majority being neutral.
   - d) Almost all of the designers agreed or strongly agreed that control communication platforms and protocols between systems need improvement (82%).
   - e) Most designers strongly agreed (87%) that "Controls always have some problems." It is not strictly a matter of whether an open source or proprietary system is used. It's a matter of writing a detailed sequence of operations, having a great relationship with your vendor and requiring accountability for integration.

**Commentary Responses**

5. What would you do again and Question 6. What advice would you offer to designers?
   - Integrate the controls sub-contractor - not just the controls.
   - Meter and monitor then track and share actual performance.
   - Design the building right first.
   - Select leading technologies and incorporate system controls for high performance.
   - Simple is smart. Keep it simple. Alternate point – Make it work.
   - Optimize settings and strategies.
7. What would you do differently?
   - Increase control contractor role and commissioning.
   - Ensure sufficient metering.
   - Consider system changes.
   - Avoid problem areas.
8. Occupants – how do you ensure they contribute to (not detract from) low-energy goals?
   - Education and training.
   - Early involvement.
   - Feedback.
   - Engagement.
9. What were the biggest project surprises?
   - Collecting energy data is rare.
   - Systems were not interoperable.
   - Contractor resistance and skills were an issue.
   - ZNE goes well beyond the traditional commissioning (Cx) process.

11. Most of the buildings surveyed were < 5 years since construction.

> The amount of energy wasted by occupants leaving lights on all the time was surprising.
> Conflicts with complex sequences emerged.
> Conflicts between system architecture and controls architecture caused problems.
> Lack of accuracy in electrical sub-meters and difficulty in setting them up was a challenge.
> There is often a lack of correlation between actual and predicted performance.
> Staging of the various outcomes, including the solar component, is challenging.
> The lack of granularity is a real problem.

10. What are emerging notable or game-changing trends for intelligent building controls?
    - Integrated and lower cost control systems.
      > The integration capabilities of end-uses and networks with automated control system management are improving.
      > The cost of interconnectivity is decreasing.
      > Adaptive and occupant-based controls and weather adaptive control settings are emerging.
    - Monitoring and feedback.
      > Building dashboards and simple monitoring systems will be significant.
      > Fault detection, with early warning for energy use or equipment failures, can have a large impact.
    - Energy Model-based Control.
    - Utility Demand Response Programs.
    - Other:
      > Robotics.
      > DC building systems.
      > Energy storage.
      > Protocol standardization.

The Ten Takeaways section of the survey not only sought to document the very important role that controls play in net zero energy buildings and the increasing value that they provide, but also allowed the survey respondents to provide feedback based on their experiences. A deeper analysis of the feedback received, and a synthesis of the recommendations reached, follows in the Conclusions section of this report.

## ES 8. 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. 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 set of buildings in this study are 23 leading edge designs incorporating a range of strategies and technologies that share a common intent to minimize energy use and get to zero net energy performance. Their design teams also share many common perspectives on the value of, and role of, controls in these buildings. Every project design firm selected 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 sub-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 sub-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, according to design firm responses, 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 the failure of components 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, as shown in this study, have more high performance systems, integrated energy production, and tend toward greater system integration, metering, monitoring and feedback as their standard practice. Due to this, research participants 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 of 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 percent less than most new buildings today and over 75 percent less than the average existing buildings, with renewables making up the small balance of energy needs. "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.[12] 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 most frequently provided through manual and automated windows (natural ventilation) and/or dedicated outside air systems. Lighting is always integrated with both daylight design strategies and controls, resulting in lighting power densities that are 40-60 percent less than a code building. The pursuit of reducing occupant-driven plug load energy remains a challenge, but well over half of the projects incorporated some control technologies such as smart power strips, outlet level controls or centralized power management, and 100 percent of them incorporated energy-use dashboards and occupant feedback. The majority of design firms attributed HVAC, lighting and plugs each with having a greater than 15 percent impact on the energy savings, so the success of the control of these systems means the success of the energy goals.

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 randomly applied (or not) by the occupant. Over half of the projects included interior shades or blinds, with a combination of manual and automated controls driven by thermal energy and occupant comfort benefits, according to the design firms.

### Occupants are a New Operator

The role of occupants on energy outcomes has never been greater. Although designers and operators see the value and importance of all system and building level controls increasing, despite reductions in baseline energy use, the occupant impact remains a wildcard. Fully 74 percent of the buildings rely on the occupant for some part of the controls success, 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 + controls where systems return to a default

12. 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.

triggered by time or sensor and messaging.[13] Yet nearly 70 percent 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.

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%) while cooling had a high unsatisfied response (40%). A majority of the respondents did want some degree of greater control modified by comments that a bit more would go a long way.

Although the issues with cooling thermal comfort were isolated to a small set of the buildings, the occupant response was strong and vocal regarding their dissatisfaction. 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. The 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 a blank section, or open ended question in interviews, in response to a 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. *"Whether through Wi-Fi, ZigBee, or EnOcean type technology, the ability of sensors to report on conditions will provide more data for the Intelligent Systems to be able to do a better job on their assigned areas."* 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. 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.

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 distributed generation (located at multiple sites and owned by a wide variety of entities) due to increased renewables on buildings and the daily/seasonal variations in energy production and use are creating new load curves for utilities and 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 change the formula for what makes sense when and where.

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.

13. "Design for Off" was developed and trademarked by Ecotope and referenced by several projects.

## 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 is the industry that manufacturers these systems, designs, builds, operates, owns or occupies buildings. 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 coupled with environmental stewardship. The implications of this study lie in the interests of the reader, yet there are clear messages that apply across most industries.

The complexity of controls in both quantity and derived data 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 and from building to energy system.

**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 buildings and increased drivers for energy efficiency. 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 Sub-Contractor**. The controls sub-contractor needs to be a primary team 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 sub-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.

Working on these recommendations through the chain of building and controls manufacturing, design, 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, efficiently and in an environmentally sound manner. Based upon the advances in design and operations of this elite class of ultra-high performance ZNE buildings, coupled with attention the buildings sector is getting from entrepreneur and tech startups in the Silicon Valley, we anticipate the pace of change in the controls industry to accelerate even more rapidly in the coming decade. It is the hope of NBI that this study is a stepping stone for effective controls in the next generation of ZNE buildings.

## ES 11. CASE STUDIES

### 1. BC Hydro: VanDusen Botanical Garden's Visitor Centre

**VanDusen Botanical Garden's Visitor Centre**

(Source: Perkins+Will; photo credit: Nic Lehoux)

**Key Highlights**

Showcases the benefits of adopting truly sustainable guiding design objectives including optimization of surplus on-site energy generation, energy exchange with neighboring buildings and integration of appropriate mechanical and innovative passive HVAC systems.

**Features**

Building systems performance optimization has been achieved through a combination of equipment design modification and ongoing commissioning and performance measurement and verification (M&V) at the whole building, systems, equipment, and end-use levels.

**Project Overview**

From small neighborhood green spaces to large destination parks and feature gardens such as VanDusen Botanical Garden, the Vancouver Board of Parks and Recreation (VBPR) maintains more than 220 parks that make up 11 percent of Vancouver's land mass. VanDusen Botanical Garden features 22 hectares of elegant landscapes with plant species representing ecosystems ranging from the Himalayas to the Mediterranean, from Louisiana swamps to the Pacific Northwest. The Garden's stunning Visitor Centre acts as a gateway to the Garden. The 19,500 square foot, single-story structure's unique organic form is based on the petal structure of a native British Columbia orchid making it one of Vancouver's most iconic buildings, and a model of sustainability.

The Visitor Centre opened in 2011 to create a striking visual impact to attract visitors to the garden. Its green roof undulations all converge at the "oculus", a skylight feature which tops the central atrium area containing information and ticket counters and informative displays. The Centre also features a library, fundraising office, gift shop, a café, an extensive volunteers' lounge, a classroom for educational programs and three flexible spaces for event rentals.

As a Leadership in Energy and Environmental Design (LEED) Certified Platinum facility, it incorporates a range of sustainable technologies including thermal mass rammed-earth walls, a green roof, passive ventilation through the oculus,

photovoltaic (PV) panels, solar hot water tubes, geoexchange heating and cooling and a heat recovery unit.

The VBPR also embraced the design team's goal to meet the "Living Building Challenge" issued by the Cascadia Chapter of the U.S. Green Building Council. As such, the Visitor Centre generates more heat than is needed from these systems and transfers excess heat to the neighboring Garden Pavilion in exchange for an equivalent amount of hydro-electric generated electricity from the grid. It is also a net zero water building employing a number of water conservation and treatment strategies and incorporates non-toxic materials along with other stringent sustainability performance prerequisites.

Perkins + Will Canada Architects, Fast + Epp Structural Engineers, Integral Group and landscape architect Cornelia Hahn Oberlander designed the project.

**Sustainable Design Objectives**

From the outset, this project was designed to be radically green to achieve the highest level of LEED certification. There would be a green roof to insulate the building and reduce water run-off and all energy needed to run the Visitor Centre would be generated on-site. However, the decision to target the Living Building Challenge raised sustainability efforts to a whole new level and had major impacts upon non-toxic material choices, carbon neutral construction, non-combustion energy generators, net zero water management and carbon neutral.

**Facility Details**

- City of Vancouver Board of Parks and Recreation.
- Address: 5251 Oak Street, Vancouver, British Columbia, Canada.
- Building Type: Assembly.
- SF of Building: 19,500 SF.
- Construction cost = $US 865/ft2.
- Comprised of a library and resource centre, gift shop, café, volunteers' lounge, fundraising office, classroom and three versatile function spaces.
- Full-time occupancy = 10. Average visitor occupancy = 50.

**Net Zero Energy and Water**

One of the green roof petals supports an array of 400 solar hot water tubes and another is a rainwater catch-basin. Passive design features include wide roof overhangs over clerestory glazing, high-thermal-mass rammed-earth walls and natural ventilation. Cooling is enabled by automated, motorized windows and driven by the stack effect up through the central atrium's "oculus" that incorporates a perforated aluminum "sun catcher" to help create the temperature differential to needed to form convection currents.

The hot water generated by the solar tubes is stored in 55 twenty-foot deep geoexchange boreholes. The zoned geoexchange system is used for space heating and cooling and domestic hot water. A heat recovery unit also maximizes the benefits from the return air that is naturally warmed and captured from the oculus or from the thermal mass of the walls.

**Sun-Catching Ventilation "Oculus"**

(Source: Vancouver Parks Board; photo credit: Kent Kallberg)

Captured rainwater is filtered through layers of natural materials and a bog and stored in a 300,000-litre custom cistern. Along with filtered greywater from the sinks, filtered rainwater is used for flushing toilets. Urinals are waterless to reduce consumption and all blackwater is treated by an on-site bioreactor.

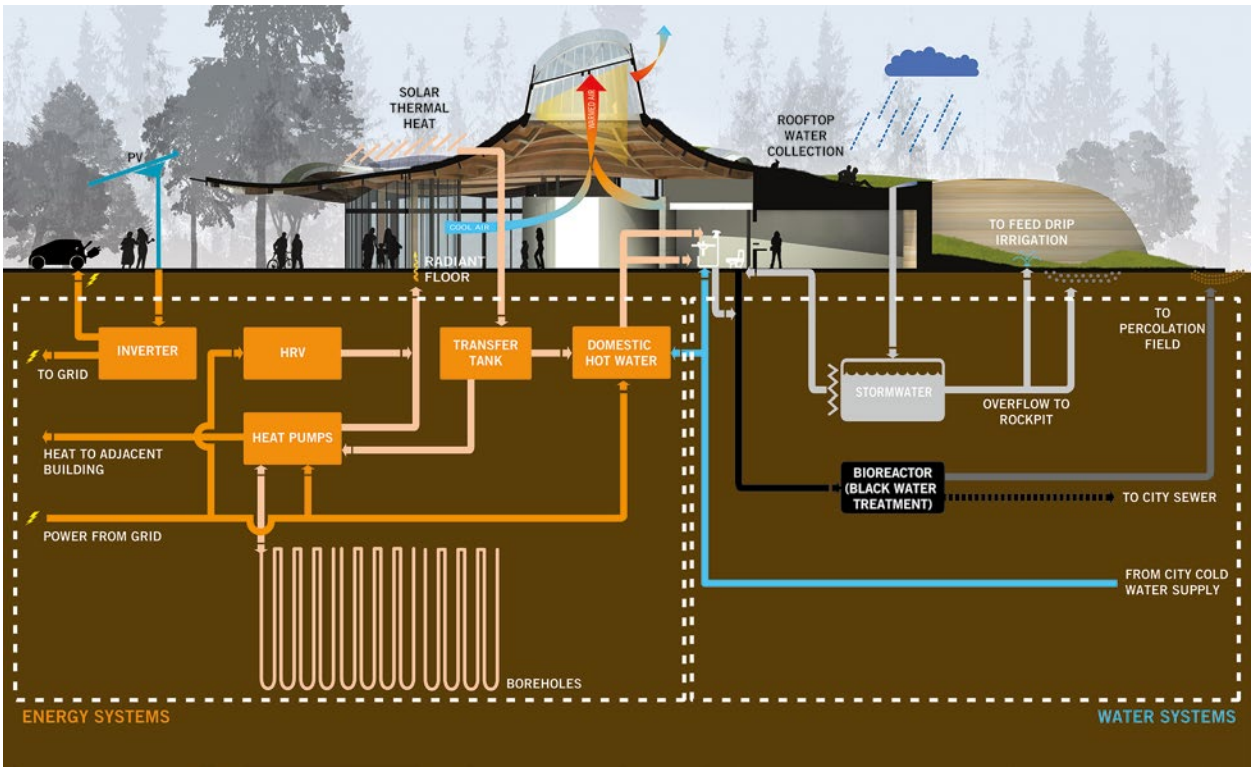
**Performance Metrics**

- Wall Thermal Resistance = R-28 (rigid).
- Roof Thermal Resistance = R-45 (sprayed).
- Floor Thermal Resistance = R-15 (rigid).
- On-Site Solar Thermal Energy Production Intensity = 32.4 kBtu/ft2/y.
- On-Site Photovoltaic Electricity Production Intensity = 9.5 kWh/ft2/y.
- Total Site Energy Use Intensity = 44.2 kBtu/ft2/y.
- Lighting Power Density (LPD) = 1.0 W/ft2 (closed loop).
- Plug Load Power Density (PLPD) = 2.8 W/ft2.

**Controls Characteristics**

The Reliable Controls BACnet building automation system's architecture consists of three central I/O panels plus one Internet-connected network panel. There are 149 hardwired inputs and 87 hardwired outputs. Operator interface is facilitated by an energy information dashboard and 18 graphical control displays. If the Visitor Centre was equipped with conventional HVAC systems, the scale of the controls would be about three times smaller in terms of I/O, programming and operator interfaces. Energy source and end-use integration includes electricity and thermal energy generation, passive ventilation, geoexchange heating/ cooling, lighting, partial plug load control and blackwater treatment.

**Mechanical Systems Schematic**




(Source: Perkins + Will)

**Lessons Learned**

- The architect and mechanical consultant must educate the controls vendor as to how the building and systems designs were developed to achieve the ZNE target.
- The controls application engineer must not take a dogmatic approach to ZNE projects – innovative design and subsequent, flexible adaptation to the building's actual thermal dynamics are essential.
- Decreasing energy loads don't allow for decreasing scope of controls hardware and software because complete automation of passive/active system integration including comprehensive energy information system feedback is critical to ZNE advancement and project success.
- As a rule of thumb, the commissioning (CMx) time allowance for a ZNE project should be three times the allowance for a corresponding conventional project.
- The controls programmer and building operator must collaborate regularly and extensively during the first four seasons of operation to modify hardware and software as required to achieve the ZNE performance target.
- Occupants must be educated as to the importance of their behavioral adaptation and actions in order to achieve the ZNE performance target.
- ZNE public assembly buildings can become victims of their own success because occupancy levels will build with popularity and energy demands will increase accordingly thereby threatening long-term realization of the ZNE performance target.

**Awards**

- 1st Place – Inaugural World Architecture News Engineering Awards (United Kingdom).
- Lieutenant Governor of British Columbia award in architecture, merit level by the Architectural Institute of BC.
- Five Vancouver Regional Construction Association Awards.
- Lieutenant Governor's Award for Engineering Excellence by the Association of Consulting Engineering Companies British Columbia.

## 2. EMerge Alliance: PNC Bank Branch, FL


**Overview**

Ft. Lauderdale, Florida is one of the sunniest locations in the United States, so it makes a lot of sense for businesses to use the great weather to their advantage by powering electrical systems with solar power. But for a PNC Bank branch, the traditional solar system they employed was too inefficient to be cost effective. That's when they turned to Nextek Power Systems. Most solar technologies take the direct current (DC) produced by photovoltaic arrays and invert it to alternating current (AC), so it can be used by existing wiring and equipment. But there is a significant power loss in the inversion from DC to AC. Plus, the power must then be converted back to DC for use in equipment that incorporates semiconductors, resulting in additional power loss. For a company that prides itself on fiscal acumen and responsibility, this strategy didn't make much sense. They asked Nextek to see what their Direct Coupling® technology could do to improve the energy situation.

**Solution**

Direct Coupling® technology utilizes DC-compatible equipment that eliminates the need for most conversions/inversions, regulating the solar array and the power to the load, thereby reducing power loss in the system, which translates to energy cost savings. Existing photovoltaic panels were employed in this project. The solar array produces between 60 – 120 VDC through a Maximum Power Point Tracking Controller to a constant output voltage for distribution through a Power Server Module. The input of the PSM combines DC power from the solar array, with AC from the grid, which is only used when needed.

**Results**

The DC photovoltaic system has successfully powered the facility, almost completely eliminating the use of grid-supplied AC power during business hours.

### 3. EnOcean Alliance: Wayne Aspinall Courthouse, CO

enocean® alliance
No Wires. No Batteries. No Limits.

Photo Credit: GSA, © David Lester Photography

**Innovative Wireless Lighting Controls**

Magnum Energy Solutions is involved in GSA's first targeted Site Net Zero, certified LEED platinum building located in Grand Junction, Colorado.

*By Cory Vanderpool, Business Development Director, Magnum Energy Solutions*

Funded by the American Recovery and Reinvestment Act, the $15M modernization and high performance green building renovation not only preserved an anchor in the Grand Junction community. It also converted the 1918 landmark into one of the most energy-efficient and sustainable historic buildings in the country.

**Integrated lighting control strategy**

Magnum Energy Solutions provided the innovative wireless lighting control strategy that was deployed in the building. This lighting solution consists of motion sensors for occupancy-based lighting control, as well as LUX sensors which measure ambient light to accomplish daylight harvesting. Lighting relays, wireless and batteryless light switches, outdoor LUX sensors and power strips were also incorporated into the project.

**Individual occupancy rules**

The entire lighting system was integrated into the building's existing Tridium-based building automation system. In addition to the various controls implemented in office areas, the common space lighting is dimmed down during periods of non-occupancy and brought up to required light levels automatically when occupancy is detected. In addition to the individualized controls, there are master schedules associated with each of the buildings tenants. The occupancy-based data that the sensors collect is also provided to the mechanical systems in the building for optimized HVAC-related control.

**Sustainable technology scores**

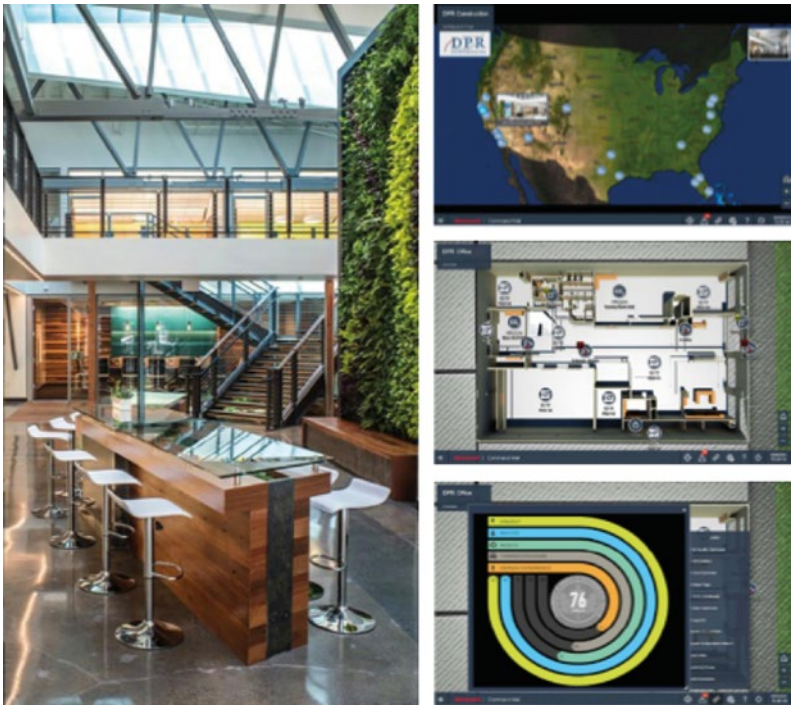
What sets this wireless lighting control system apart is that the devices utilized are not only wireless, but also battery-less. By utilizing the open, interoperable EnOcean radio protocol, occupancy sensors utilized in the building are "powered" from small solar cells that harvest available light in the space, which is a much more sustainable solution. With no wires to run and no batteries to replace, Magnum's technology allowed for the building to achieve additional LEED-related points and will have substantially less ongoing maintenance than a wireless solution requiring batteries.

www.magnumenergysolutions.com

## 4. Honeywell: DPR Construction San Francisco Office, CA

Honeywell

**DPR Construction San Francisco Office – Honeywell Building Solutions**



**Key Highlights**

Integrated building controls and highly visual, easy-to-use technologies from Honeywell are enabling the San Francisco office of DPR Construction to optimize building efficiency, drive sustainable behaviors and ultimately help establish it as the first zero net energy building in the city.

**Features**

The use of integrated technologies, including Honeywell Enterprise Buildings Integrator (EBI), a building management system, integrated fire and life safety systems, plus access control and digital video, help establish an automated building controls environment for optimal efficiency. Layered on top are key visualization technologies, including the Honeywell Command Wall, which features system-wide control from a single, intuitive touchscreen interface, as well as the LEED Dynamic Plaque, a near-real-time monitoring tool that measures and provide performance feedback to help optimize operations and deepen facility sustainability.

The facility also features a 118 kilowatt photovoltaic (PV) system, a View Dynamic Glazing skylight, rooftop solar thermal water heating, a Solatube day-lighting system, Velux solar-powered, automated operable skylights, 13 fans that efficiently promote air flow, three "living walls" featuring live plants, and reclaimed redwood and douglas fir. Combined, these integrated, efficient and sustainable products and technologies are helping the San Francisco office produce as much or more energy than it consumes.

**Project Overview**

DPR Construction, a national technical builder specializing in highly complex and sustainable projects, aims to be as environmentally responsible as possible in the way it does business — and this passion for sustainability extends to what the company builds, and how it runs its regional offices and jobsites. As such, when the company sought to develop a new San Francisco office, it embraced practicing what it preaches, and aimed to create a living lab for sustainability within the office, testing the newest and most intelligent building and energy efficiency technologies available with the help of companies such as Honeywell.

In five months, the DPR Construction team researched, designed, permitted and built the highly-efficient, 24,000-square-foot modern workplace with a number of sustainability features. It is now on track to become the first zero net energy building in the city, thanks to its highly sustainable design and its use of the most innovative technologies to ensure optimal energy performance.

**Facility Details**

- Client: DPR Construction.
- Address: 945 Front Street, San Francisco, CA, 94111.
- Building Occupants: 2 floors, 60 occupants with lease space.
- Square Feet (SF) of Building: 24,000 SF.
- Building Type: Office.

**Integrated Technologies from Honeywell**

To achieve its sustainability goals, DPR Construction is using integrated controls to automate core building functions, and highly-visible displays and management tools to increase occupant engagement in helping drive office-wide sustainability.

At its core, DPR Construction uses Honeywell Enterprise Buildings Integrator (EBI), a building management system, which helps facilitate the integration of security, comfort, life safety and energy systems, among other functions. EBI also gives users a single point of access and consistent view to building-wide information and resources, enabling easy identification of areas for optimization.

Data from EBI at DPR Construction also powers the LEED Dynamic Plaque from the U.S. Green Building Council (USGBC). This near real-time monitoring tool measures and provides performance feedback to the LEED-certified building. It assesses the building's performance in the categories of energy use, water consumption, waste output, occupant transportation and human experience, aggregating data to provide an overall performance score that reflects the LEED

rating system. By integrating with Honeywell technology, the plaque automatically receives information from core building systems that contribute to a facility's LEED performance score, in addition to input from occupant surveys and waste tracking information. The score updates as data feeds in and can raise awareness of likely issues — and potential fixes — that could affect operations.

The LEED Dynamic Plaque not only helps with LEED recertification, but also plays a critical role in helping DPR Construction meet its commitment to becoming a zero net energy facility. DPR Construction mounted the appealing and easy-to-understand plaque in its lobby so tenants and guests can view and better understand the building's ongoing rating — and see the implications of their everyday actions, helping drive and encourage sustainability-focused behaviors. It also features an app for access from anywhere, helping incentivize occupants to engage in actions that can positively impact sustainability.

To help further optimize operations and building efficiency, DPR Construction also uses the Honeywell Command Wall, part of the Honeywell Command and Control Suite, to easily visualize building operations and boost performance. The Command Wall, a sci-fi-like operator interface built with the intuitive, consumer-friendly simplicity of tablets and smartphones, integrates with Honeywell EBI, and features map-based visualization and navigation, along with integrated workflows. Pulling data from EBI, it presents information in an easy-to understand way while providing context for more informed decision making. Users can access an enterprise-wide view and also easily zoom into specific areas to quickly understand and react to issues and opportunities as they arise — empowering DPR Construction to continuously optimize building strategies to drive toward its zero net energy goal.

**Project Stages**

The DPR Construction team researched, designed, permitted and built the highly-efficient, 24,000-square-foot workplace with a number of sustainability features within five months through detailed planning and coordination with key vendors, including Honeywell. In first seeking out the space, the team identified locations with the right features to accommodate the company's objectives, including optimal roof space for photovoltaic panels and a significant amount of natural lighting.

The accelerated design/build process involved thorough and detailed planning with Honeywell to ensure optimal building controls integration, including critical infrastructure planning and coding to help DPR Construction get the most out of its building systems and technologies. This planning also entailed understanding downstream data needs to support facility operations, selecting the right systems and planning for energy modeling.

Commissioning also played a critical part in the project. The project team employed continual commissioning and benefited from having an enterprise-wide view to optimize operations, and ensure adequate preparation for getting the building up and running. The commissioning process also involved ample communications with — and participation from — occupants in order to maximize comfort. This included driving awareness around expanding individual thermal comfort profiles, and educating occupants on the organization's overall zero net energy commitment and the requirements to meet it. This involved changing behaviors, and helping occupants understand the realities of their new space and everyone's individual contributions to the organizational goals. When DPR Construction moved into the space, for example, all employees received a gift bag including items to encourage sustainable behaviors, such as water bottles and blankets.

DPR Construction also took steps to maximize occupant engagement and accountability around sustainability through the use of tools such as the LEED Dynamic Plaque. This included keeping occupants informed of all building developments and efforts to achieve the zero net target. And, on the operator side, DPR Construction gave multiple individuals system administrator rights to ensure someone on the facility team is able to constantly glean feedback from the integrated systems and easily make necessary modifications in real time.

**Key Achievements**

- In its first year of operation, the building produced 15 percent more energy than it used.
- Design energy use intensity was 22 and the actual was 21.
- The building is on track to reduce its carbon footprint by 37 percent by the end of 2015, exceeding its initial reduction goal of 25 percent.

- The building has become an award-winning space, earning Project of the Year and Best Green Project award (2014) accolades from ENR California, the Merritt Award for Sustainability (2015) from the International Interior Design Association (IIDA), and the Peoples' Choice Award (2015) from IIDA.
- The integrated building systems have set the stage for additional savings opportunities in the future, including participation in the local utility's automated demand response program.

**Lessons Learned**

- A commitment to innovation at the start of a project pays dividends in achieving zero net energy.
- No two buildings are alike — especially when making renovations to existing structures—and each site must follow its own path to achieving zero net status.
- An optimal project design takes into account factors such as total cost of ownership, setting a strict payback period, local codes, and available rebates and incentives.
- Employees drive building performance and are important to achieving the goal of zero net energy use so their participation and support are key. Making occupants part of the sustainability effort, while working to ensure their comfort and satisfaction, drives engagement and, in turn, overall building performance.

### 5. Schneider Electric: The Edge Building

**Schneider Electric helps make The Edge "the world's most sustainable office building" SmartStruxure™ solution BMS, electrical distribution and field devices ensure energy and operational efficiency**

Located in Zuidas, Europe's fastest growing business and knowledge district, The Edge in Amsterdam, The Netherlands, is heralded as the world's most sustainable office building. Officially opened in May 2015, this 40,000 m2 multi-tenant, Class A office building was conceived by OVG Real Estate, a Dutch commercial real estate developer committed to green development, in partnership with Deloitte, a global professional services firm and the building's primary occupant.

**Open and flexible architecture**

The Edge is designed according to 'The New World of Work' principles, which challenges traditional organizational culture to create an agile, high-performance workplace where innovation can thrive in an open and flexible environment. Adhering to that philosophy, The Edge is designed with a breathtaking glass exterior and large, open floor plans situated in a U-shape around a majestic 15-story, north-facing atrium. The atrium is surrounded by balconies and residents can easily move between levels to gather in naturally-lighted meeting areas.

**Technically as well as visually impressive**

A marvel of architectural design, behind the scenes at The Edge is a comprehensive array of building engineering and energy efficiency ecosystems that make it outstanding both operationally and environmentally, as well as aesthetically.

A broad range of Schneider Electric integrated building management solutions, electrical distribution systems, and IT infrastructure are employed throughout The Edge. Schneider Electric was pleased to unite once again with OVG at The Edge following their successful collaborations a few years earlier at the carbon-neutral TNT Centre (Hoofddorp, The Netherlands). They also introduced OVG to the project's lead system integrator, HC Groep.

A transversal team from Schneider Electric EcoBuilding Division and Partner Business served as liaisons between Schneider Electric entities and several other well-respected participants in their industries, including: primary end user (Deloitte); engineering consultant and specifier (Deerns); and contractor (Homij Bosman Combinatie), as well as other integrators and panel builders.

"During the bidding process we worked closely with Schneider Electric to ensure that the newest building automation technology was available and could be integrated in all the emerging new technology in The Edge," says Jacob Jansen, General Manager of HC Groep, a leading system integrator in The Netherlands for 25 years. "Because of the important scope of this project, a mock-up was built in our climate laboratory to demonstrate the feasibility and integration options."

**Smart Building Approach**

SmartStruxure™ solution, Schneider Electric's premier building management system (BMS) powered by StruxureWare™ Building Operation software, is used at The Edge, including 50 Automation Servers. BMS-compatible field devices are installed in ceilings and in technical rooms, including sensors, valves, actuators and heat meters, which provide energy related measurement of thermal energy used in the building.

The Edge facility managers are able to manage building operations and energy use on-site or remotely to maintain optimal comfort for occupants. Access to critical building data is available via easy-to-use dashboards and advanced reporting to make information-based decisions to optimize HVAC energy use and reduce waste.

**Cool air from the ground floor at The Edge is circulated to the top of the atrium to thermo wheels then released to the outside.**

Schneider Electric electrical distribution products are also used throughout the building, including electrical panels, busbars, energy meters and frequency drives located in technical rooms. Over 180 energy and heat meters are installed in the building and energy measurement information is captured in StruxureWare Power Monitoring Expert software.

"This was a very complex job and Schneider Electric demonstrated that we have a full complement of vision and expertise as well as products, systems and solutions to help simplify the entire experience for our customers," said Erik Zwaan, EcoBuilding Commercial Manager at Schneider Electric in The Netherlands. "The success at this impressive edifice, including a full spectrum of building ecosystems, demonstrates our comprehensive team approach and ability to deliver results as a true multi-faceted project management organization." The Edge also features other impressive building efficiency measures: It is the first building to utilize a third party's Ethernet-powered LED connected lighting, which enables employees to use an application on their smartphones to regulate the lighting and climate in their individual workspaces. This innovative technology not only saves money on energy costs, but also provides information and data analytics about how the building is running.

The Edge is also a net zero energy building. To achieve this, the south façade is fitted with solar panels on all non-window surfaces. Additionally, aquifer thermal energy storage (approximately 130 m below ground) generates all energy required for building heating and cooling. Rainwater harvesting, electric vehicle charging stations, and motion-sensored ventilation are some of the other eco-friendly features at The Edge.

**Estimated energy consumption at The Edge is less than 0.3 kWh/m²/yr.**

**The customized integrated system allows building and facility managers to monitor, measure and control – in a single view – the building's HVAC and room control systems, as well as its state-of-the-art aquifer thermal energy storage and solar-generated energy.**

**"Sustainability is about more than a great BREEAM rating. It is also about a building's overall comfort and efficiency for its occupants, so that they can operate with ease in a productive and healthy environment."**

***– Coen van Oostrom,***
***Founder adn CEO of OVG Real Estate***

**A feat of modern engineering and sustainability**

The Edge not only sets a new global benchmark for the built environment, but also prioritizes the comfort, health and productivity of its occupants. Schneider Electric was able to partner directly with the property developer, lead occupant, specifier, system integrator and other essential participants from the early stages of the project. Schneider Electric's energy management expertise and ability to understand and plan for the life cycle of the building helped The Edge earn the highest score ever awarded by the Building Research Establishment (BRE®) – 98.36 percent – and the distinction of BREEAM® NL New Construction certification of 'Outstanding.'

## SECTION 1

# INTRODUCTION

### About This Report

The Continental Automated Buildings Association (CABA) commissioned New Buildings Institute (NBI) to conduct research on controls in Zero Net Energy commercial buildings.[14] ZNE buildings are an emerging trend in response to energy efficiency and carbon reduction policies, as well as market interest in 'green and sustainable' environments. NBI's last decade of work in building performance outcomes and ZNE buildings identified a gap in information concerning the control systems applied in these leading edge buildings. The outcomes of this collaborative research project can help fill that gap and enable a better understanding for CABA, its members, and the building and energy industry. The findings can help: manufacturers target improvements; design teams better integrate controls and work with contractors more effectively; and utilities identify program priorities leading to a next generation of buildings on the path to zero. The research was conducted from December 2014 to September 2015 with a final webinar presentation in November 2015.

**Note**: An Executive Summary is available as a stand-alone report and available at www.caba.org and www.newbuildings.org

### Role of the Steering Committee

The Steering Committee represents a cross-section of providers in the energy and building controls marketplace. Representatives from each organization joined NBI and CABA on regular collaboration calls to guide the research scope and ensure it met project objectives. Figure 11 shows the 18 companies and organizations that were on the Steering Committee and supported this project.

**Figure 11: Project Steering Committee and Funders**

14. Also called Net Zero Energy or Zero Energy buildings.

### About CABA

The Continental Automated Buildings Association (CABA) is an international not-for-profit industry association, founded in 1988, dedicated to the advancement of connected home and building technologies. The organization is supported by an international membership of over 325 organizations involved in the design, manufacture, installation and retailing of products relating to home automation and building automation. Public organizations, including utilities and government are also members. CABA's mandate includes providing its members with networking and market research opportunities. CABA also encourages the development of industry standards and protocols, and leads cross-industry initiatives.

Please visit http://www.caba.org for more information.

### About NBI

New Buildings Institute (NBI) is a non-profit organization working to improve the energy performance of commercial buildings. As a technical resource for governments, utilities, energy efficiency advocates and the building industry, NBI acts as a carrier of ideas between these groups and works collaboratively to put the best innovations for advanced buildings into action. Our primary work areas are focused on creating the thought leadership that defines "What's Next" in our industry, assessing effectiveness of emerging technologies, promoting best practice design approaches and helping to guide policies and programs that will significantly improve the energy efficiency of commercial buildings.

### The Research Team

New Buildings Institute had several research partners that supported the project and were essential to parts of the research results. Figure 12 shows the six entities that had partnership roles in this study.

Figure 12: Research Team

## INTRODUCTION

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. The building and system-level controls can be a cornerstone that secures performance, or a weak link that creates challenges for design teams and operators. ZNE buildings are now at the forefront of energy efficient design and operations, yet little is known regarding energy-related control systems in these advanced structures. This project focused on the control aspects in ZNE buildings.

### Key Objectives

The objective was to characterize monitoring and control systems in zero net energy buildings focused on three key areas from the designer and user experience. The research outcomes will be widely published and used to influence controls design, installation, operations and occupant engagement.

**Three key objectives:**

1) **The Design, Selection and the System**. What did they 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 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 to low energy targets were various systems in these buildings?
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 Database* and the findings in the 2014 *Getting to Zero Status Update* (ZNE Update).[15, 16] 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. The research team and Steering Committee identified the priority building types and reviewed the areas of inquiry for the surveys. The surveys were conducted in person, via phone and/or through an online link. The research team identified an initial target list of over 60 projects and design teams and did extensive outreach to get the research target of 20+ building projects.

## Surveys

Survey questions were in a variety of formats including yes/no, ranking, multiple choice, with the ability to select more than one response in some cases, and narrative response. In all cases a comment box was available on the Web survey and interviewers prompted dialog on the topics.

The research was targeted to parties responsible for the selection, operation and utilization of the control systems. These parties are:

- Design Firms (architect and engineering)
- Operators
- Occupants

The surveys were applied either online or through direct interviews using a survey instrument with over 100 customized questions for the design teams and operators broken into the following topics:

I. About You
J. Takeaways and Lessons Learned
K. Building Information
L. Energy Performance
M. Control System Description and Characteristics
N. Design Process
O. Control Selection Process
P. Building Handoff and Post Occupancy

The occupant survey was distributed to dozens of buildings – those with ZNE buildings that participated in the design research portion of this project and occupants of other ZNE buildings as well and responses received from occupants of seven buildings. The surveys focused on the awareness of the occupant to energy targets. An additional set of responses from a group of occupants from an office space that was upgraded to be highly energy efficient and representative of an equivalent space to ZNE are also included. The survey took fewer than 10 minutes and responses were anonymous.

## Report Structure

This report is organized to address the findings around the key topic areas of the survey. Broader information on the buildings will benefit the larger ZNE database but was beyond the controls focus of this scope. With a diverse range of buildings

15. The Getting to Zero Database is a publicly available resources with information and case studies on ZNE buildings. http://newbuildings.org/getting-to-zero-database.
16. Available at: http://newbuildings.org//2014-zne-update.

and respondents the research team has worked to consolidate the results to logically inform the project objectives in a transparent manner.

The report notes the variation in responses and attempts to represent the range and commonalities of the survey participants. The report draws from survey responses and comments or interviews. Although the buildings included in the survey are identified by name at the front of Chapter 2 the buildings are assigned letters in the survey results to anonymize the data per the agreement with the survey participants.

In addition to the Executive Summary, this main report has the following chapters on the research results:

1. Introduction
2. Getting to Zero
3. Participant Characteristics
4. Types of Controls
5. Control Selection Process
6. Operations and Occupancy Factors
7. Energy Impacts
8. Ten Takeaways
9. Conclusions
10. Appendices

CABA and NBI welcome input and inquiry regarding the findings of this study as well as references to other leading resources, buildings or firms. The work of Getting to Zero for the majority of buildings in North America is a long road and your distribution of this report and contribution to ongoing efforts is important.

## SECTION 2

# GETTING TO ZERO

A background and overview of ZNE buildings and trends will help frame the context of this study and the buildings and entities involved.

### BACKGROUND

The real estate industry has been riding a wave of green building over the past 15-20 years. LEED, Green Globes or LEED equivalent buildings are now standard practice in many markets and required by policy in others.[17] 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 nonresidential building attempting to get to net zero in the U.S. was built over 15 years ago as a demonstration effort at a university.[18] Slowly, other universities, public buildings, and non-profits followed suit with small examples of the feasibility of ZNE.

Today the ZNE model has moved beyond these demonstration-type 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 – *The Getting to Zero Status Update* – has been conducted by NBI three times over the past 10 years documenting this growth and the trends of ZNE buildings. NBI now has documentation on 225 buildings achieving or striving for net zero, 20 percent of which are building renovations demonstrating that even existing buildings can be transformed to achieve low or zero energy performance. NBI also maintains the largest database in North America of ZNE buildings which serves as a public resource of specific information on a per-building level.[19]

These buildings rely on building and system-level energy controls, monitoring, energy management, and operator/tenant feedback to help meet their low energy use goals. While this is of little surprise given the growth in the use of these systems across all (and particularly high performance) commercial buildings, the adoption of ZNE standards in buildings is looked to as a best practice among leading owners and practitioners.

### THE MEANING OF "ZERO"

Words and definitions can cause clarity or confusion yet there is no arguing that the vernacular on this topic is wide and variable. In North America, as well as world-wide, getting buildings to the lowest possible energy use and offsetting that energy use through renewable energy is a commonly accepted practice and growing interest. Commonality of terminology, however, is not easy to find and nuances, objectives, policies and opinions alter the details of the words "Zero" "Net" and "Energy".

NBI recognizes the benefit of consistent terms but also the reality of preferences and need for diversity to address varying scenarios and entities. The topic of terms and definitions is evolving at the international, national, regional, and state levels including a recent release on Zero Energy definitions by the U.S. Department of Energy[20]. The definitions used by NBI for this study and our work in ZNE commercial buildings are summarized below.

17. The U.S. Green Building Council's Leadership in Energy and Environmental Design (LEED).
18 Oberlin College University Center, 13,600 square feet, built in 2000 and modified for over a decade before achieving actual net zero energy performance.
19. Available at http://newbuildings.org/getting-to-zero-buildings-database. 20. Available at http://energy.gov/eere/buildings/downloads/common-definition-zero-energy-buildings.

## Zero Net Energy Fundamentals

This section briefly breaks down some the terms and explains the formula to calculate if a building is net zero.

- **Zero Net Energy (ZNE) Buildings** – ZNE buildings have greatly reduced energy loads such that, over a year, 100 percent of the building's annual energy use can be met with onsite renewable energy.
- **Zero** – This means 'nothing' – plain and simple.
- **Net** – A result from combining more than one item. In this case from energy used in the building and energy produced in the building. If the energy used by the building is completely (or more) replaced by energy produced by renewable sources at the building and/or building site, then the building's energy use is 'net' zero. Remember, energy use and production are constantly changing so the 'net' varies widely over the year. For this reason 'net' is calculated as an average over 12 months.
- **Energy** – Energy means all energy (electric, gas, steam, liquid fuel, etc.) consumed at the building interior and exterior (typically lights metered with the building such as entry lights, walkways, signage, etc.).[21]
- **Energy Use Intensity (EUI)** – In order to normalize the various fuels in a building, all the energy forms for both use and production/generation are converted to thousands (k) of British Thermal Units (Btu) and then divided by the square feet (sf) of the building with 'yr' representing the 12 month period of data. The EUI is expressed as kBtu/sf/yr and is the most commonly used metric of a building's energy use or performance and allows benchmarking and comparisons of buildings.
- **The ABC Equation** – You simply need three things to calculate net energy: (A - B = C in (A) 12 months of Building Energy Use in kBtu/sf/yr – (B) 12 months of Onsite Renewable Production in kBtu/sf/yr = (C) Annual Net Energy Use Intensity (EUI) in kBtu/sf/yr
- **Figure 13**: (A) The Annual Energy Use of the Building from all fuels is always the starting place and is an important single metric since it represents the true total energy use of the building.[22] Then deduct (B) the Renewable Production onsite to get (C) the Annual Net Energy Use.

Figure 13: Equation for Zero Net Energy

**(A) 12 months of Building Energy Use in kBtu/sf/yr – (B) 12 months of Onsite Renewable Production in kBtu/sf/yr = (C) Annual Net Energy Use Intensity (EUI) in kBtu/sf/yr**

In Figure 14 the building uses only 15 kBtu/sf/yr and produces renewable energy equal to 17 kBtu/sf/yr so the building has a resulting EUI that is zero or less (-2 in this example).

Figure 14: Example EUI Calculation for ZNE


- **ZNE Status** – Lastly, ZNE can be a goal during design concept, a target set and applied through energy modeling or an actual metered result after 12 or more months of energy data and occupancy. In order to distinguish between buildings that are 'targeting" ZNE versus those that have 'accomplished' ZNE, NBI uses the following terms, all of which apply to Districts or Communities (groups of buildings) as well as individual buildings:

21. The inclusion of parking lot lighting or other larger outdoor energy use varies by project since it is often separately metered.
22. The calculation includes the sum of all energy use (electric, gas, steam, liquid fuels, etc.) at the building. Other definitions may not allow any gas use and infer that this is "zero carbon' while others only consider the electric energy use and define it as 'Zero Net Electric'. The allowance and inclusion of all energy in the formula is the most widely adopted - example entities are the U.S. Department of Energy, the State of California and the Pacific Coast Collaborative (made up of British Columbia, Washington, Oregon and California) and others.

> **ZNE Verified** - Documented to have met, over the course of a year, all net energy use through onsite renewables.
> **ZNE Emerging** - Have a publically stated goal of ZNE, but do not yet meet the definition of ZNE verified. These may be in the planning or design phase, under construction or have been in operation for less than a year. Others may have been operating for 12 months or much longer, but their measured energy has either yet to achieve net zero or the measured data to document verified status was not available.
> **Low Energy or Near Zero** – These buildings are comparable to ZNE buildings based on type, energy use, design strategies and technologies but do not have a stated goal of ZNE and do not meet all their energy needs with onsite renewables, although they may have renewable resources onsite. In some cases they have provided the structure and wiring that will easily incorporate renewable energy at a later date.

This study of controls in ZNE buildings includes both verified and emerging ZNE buildings. In some cases information or surveys from low energy buildings was also used since the building design and outcomes are the same as ZNE with the exception of the renewables.

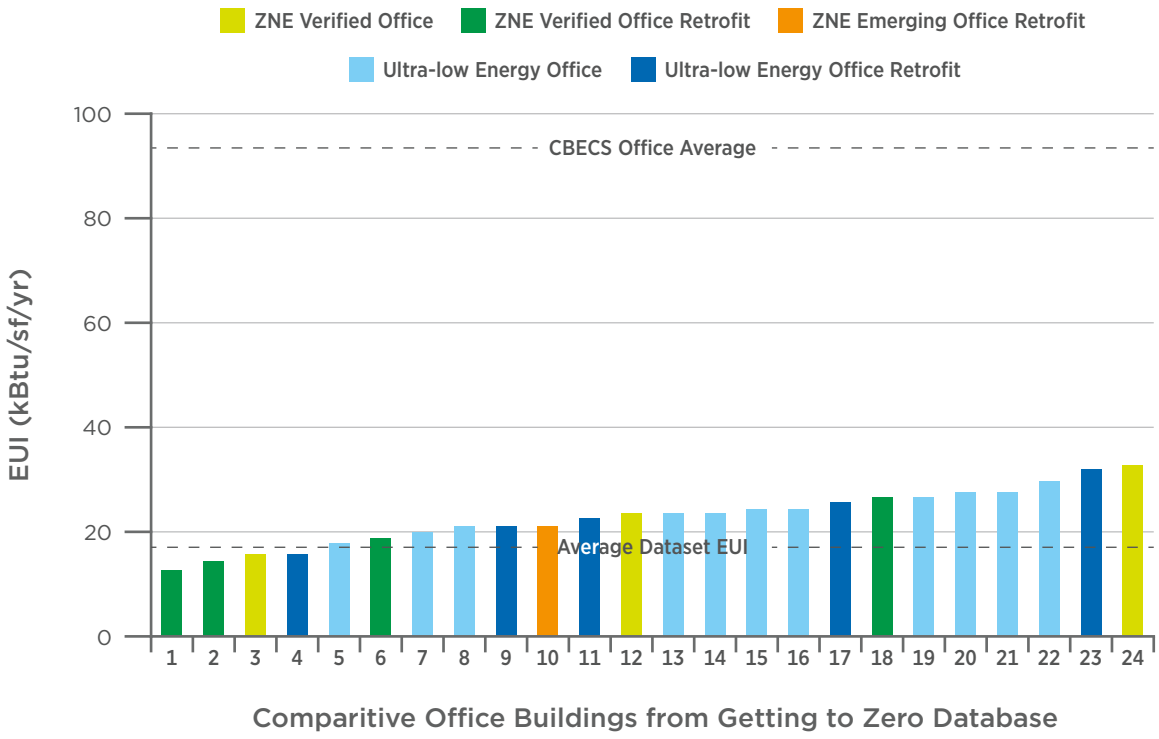
For a primer on the topic of ZNE and definitions see the Reference Section.

## Example ZNE Building Energy Use Intensities (EUI)

To be designated as ZNE Verified, buildings must operate, and not simply be designed, at very low levels of energy use. For example, while the average U.S. office building has an Energy Use Intensity (EUI) of 93 kBtu/sf/yr, NBI's ZNE dataset averages **an EUI of just 19 kBTU/sf/yr for offices – 75 percent less than the American average and less than half a typical new code constructed office building** (Figure 15).

How did they get there? In many cases the building teams cited aggressive energy targets, their building monitoring and control system, and feedback as critical to achieving their goals.

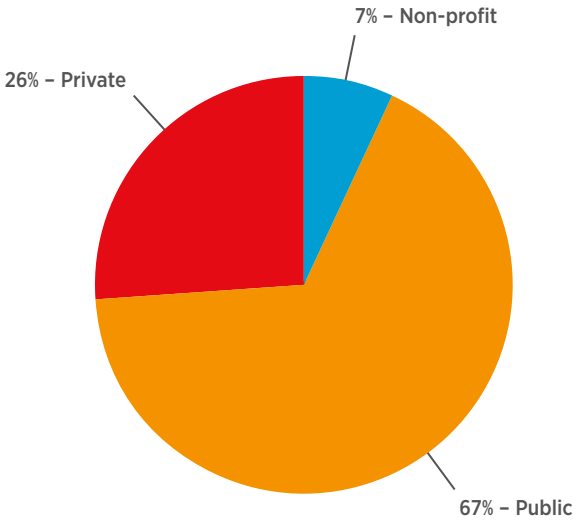
Figure 15: Measured EUI of ZNE and Low-Energy Offices from Getting to Zero Database



## ZNE SNAPSHOT AND TRENDS

The findings from the 2014 ZNE Update showed an important trend regarding ZNE building ownership and development. Of the 180 buildings in the database during that study, over a quarter were developed by the private sector (Figure 16) – reflecting that ZNE is no longer a demonstration limited to small non-profits or universities. There are also a wide range of sizes (20% are >50,000 sf), diverse building types (13 total types) and locations in every climate zone (40 states and two provinces in North America [Figure 19]).

Figure 16: Ownership Type of ZNE Buildings

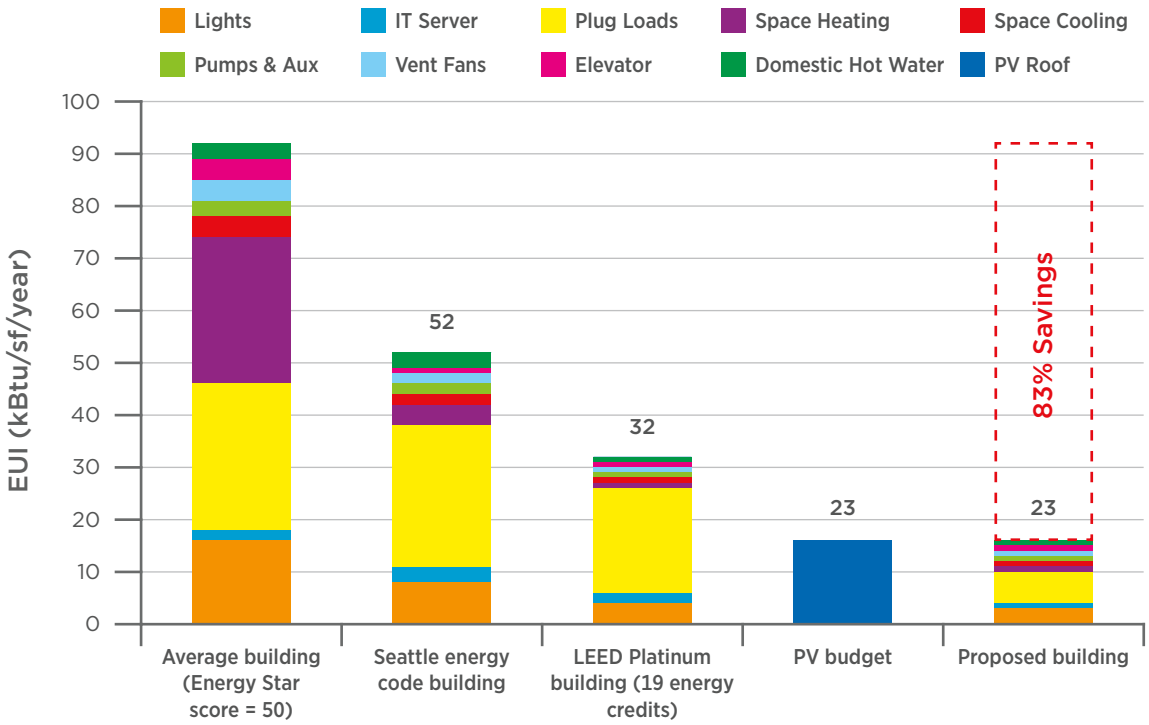



## HOW TO GET TO ZERO

Getting a building to ZNE is a mastery of many factors. From the commitment of the owner, advocacy and diligence of the design team, iterations of the energy modeler to the selection of equipment, installation, commissioning, and finally, to the ongoing operations and occupancy. The players are many and the puzzle complex. Yet there are 225 documented buildings in North America of varying sizes, types and locations with a wide range of equipment and design have targeted or accomplished ZNE. What they apply is a series of targets, strategies, designs, technologies, and ultimately, committed continuous improvement to create buildings that are performance exemplars. The beauty of these buildings is that the energy design is almost always complimented by (as well as partly responsible for) exceptional indoor environments full of natural daylight, fresh air, thermal comfort and visual elements such as views and natural materials. Getting to Zero can be synonymous with getting a better environment for occupants.

An example of a building design evolution is shown in Figure 17. In this Seattle building, the engineering firm worked to reduce loads in a range of areas well below an average building and the code building. The figure shows how they accomplished an 83 percent reduction over the energy typically used for the sum of the building systems arriving at a modeled EUI of just 15 kBtu/sf/yr.

Figure 17: Energy Use Reductions to Get to Net Zero – Seattle, WA




(Courtesy PAE Engineers)

The building in Figure 17 now has over 12 months of metered data and exceeded the EUI of 14 kBtu/sf/yr and is operating at a an EUI of just 10 kBtu/sf/yr with renewable production of 14 kBtu/sf/yr. This results in a ZNE Verified building with a net building EUI of – 4 (production exceeded use by 4 kBtu/sf/yr).

Figure 18: Metered Energy Metrics from a Building in Seattle, WA


The approaches to get to zero in the 2014 Getting to Zero Status Update include the three areas of: 1) Design Strategies, 2) Technologies and 3) Operations and Occupancy. These approaches are not universal but represent the methods used by the larger dataset of ZNE buildings in the summary.

The buildings in this controls study are summarized in the subsequent section. While the inquiry included broad questions on their systems and strategies the focus of the study is on controls – an area not well captured in the lists below from the 2014 ZNE Update.

## Summary of Methods to Get to Zero from the 2014 ZNE Status Update Report

**Design Strategies used to get to ZNE performance**

- Energy performance target set at the start.
- Integrated design approach.

- Champion(s) and experienced team to provide vision and leadership.
- Site orientation, building configuration and space planning optimized for daylight access and passive strategies.
- Improved envelope performance.
- Window glazing type, ratio to walls, size and orientation optimized.
- Exterior window shading used to reduce peak day sun, thermal and glare impacts.
- Interior design incorporated light shelves, automated blinds, light colors and low partitions.
- Stairways made to attract and facilitate movement within the building, reduce transport energy.

**Snapshot of technologies used in low and zero energy buildings**

- High performance HVAC systems. Ground-source heat pumps, radiant heating and cooling (supplied by heat pumps, condensing natural gas boilers, chillers, and other sources), chilled beams, energy recovery ventilation, natural ventilation, operable windows, night flush of the thermal mass, demand controlled ventilation (DCV) through CO2 monitoring, variable refrigerant flow (VRF) systems with dedicated outside-air systems for ventilation (DOAS), underfloor air distribution, ice storage, evaporative cooling.
- Advanced Lighting and Controls. Efficient design with low lighting power density (LPD), daylight photosensor controls, occupancy sensors, luminaire-level controls, layered design strategies with task, ambient and common areas, LED task lights, T5 fluorescent lamps, skylights, clerestories.
- Monitoring and Feedback. Wiring for system-level monitoring, energy information and building automation systems, metering, diagnostics, key performance indicator dashboards.
- Renewables. Photovoltaics on the building or adjacent to the site, solar thermal for domestic hot water, and some site wind turbines used to supplement PVs.

**Operations and Occupancy Strategies**

- ZNE and continuous commissioning.
- Energy monitoring system and dashboards.
- Plug load assessment and purchasing of low plug load equipment.
- Controlled Plug Load at the circuit, through IT department, and with power strips.
- Occupant engagement and feedback.
- Server Closet / Data Center efficiencies.
- Top Ten and Energy Star equipment/appliances.
- Green leases.

For extensive information on the trends, designs, buildings, technologies, and energy outcomes of ZNE buildings see the NBI 2014 Getting to Zero Status Update Report and other resources in the References Section of the Appendix.

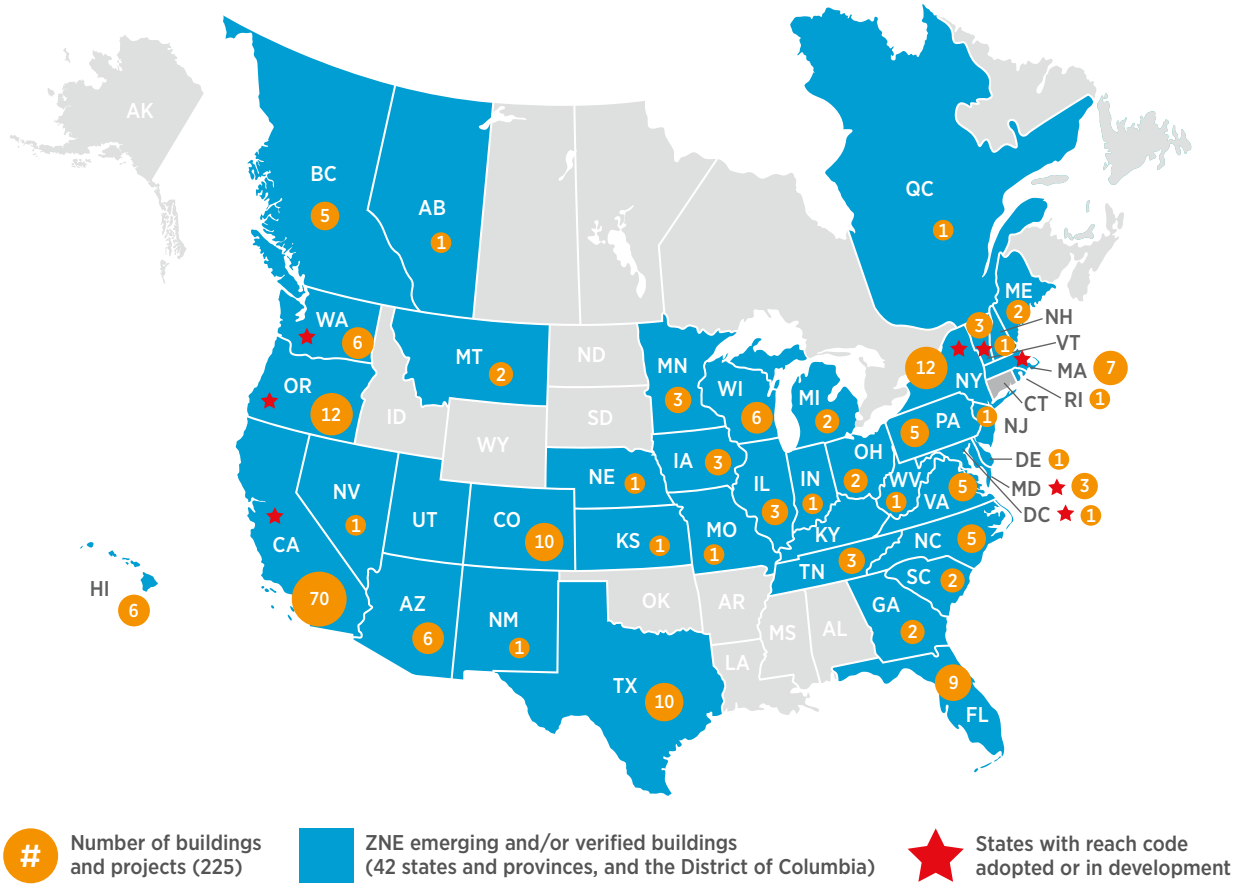
## ZNE POLICIES

Cities and states, as well as corporations, foundations, and investment firms have mandates to reduce carbon emissions towards mitigating climate change. The construction of ZNE buildings as a pathway to lower carbon emissions is already an adopted goal in California, in which new state facilities move to ZNE in 2020-2025, and all new and 50 percent of existing, commercial buildings statewide are to be ZNE by 2030. California's 2013 Title 24 building energy efficiency standards are 30 percent more stringent than existing standards; this is driven by the state's ZNE goal. Vancouver, British Columbia has likewise adopted a policy to be Carbon Neutral by 2050.

Similar policies for ZNE and/or performance-based energy codes are in place or underway in Colorado, Massachusetts, Minnesota, New Mexico, Vermont and Washington – as well as many large and small cities across the continent. Although the number of ZNE buildings today remains small as a proportion of overall commercial floor space, it is trending upward with compelling leaders out front, demonstrating practical market leadership as advocates for the benefits of ZNE. As the pressure to cut carbon increases, building energy use – which is the single greatest contributor to carbon emissions in the

U.S.[23] – will be in the spotlight, and controls will be found in the center of that focal point. Figure 19 shows how extensive the locations of ZNE buildings have become and which states or provinces have adopted or are considering advanced codes.

Figure 19: Locations of ZNE Buildings and Reach Codes[24]

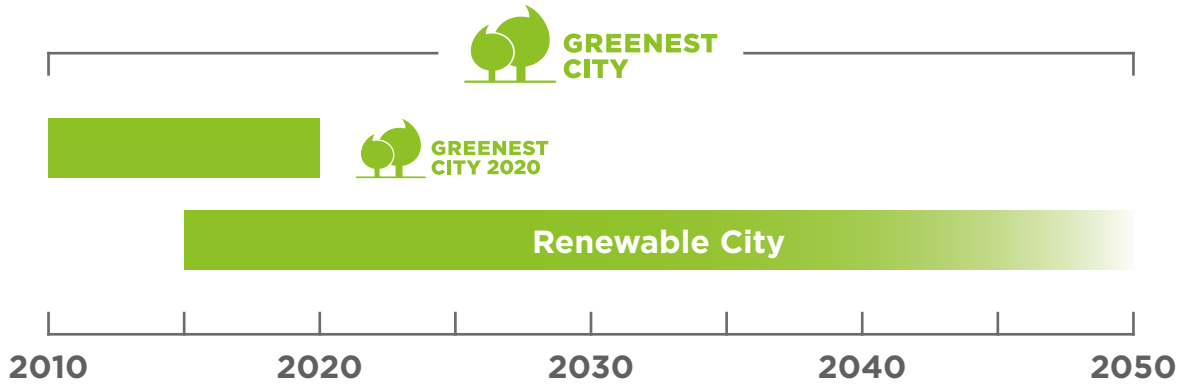



In 2010, Vancouver, British Columbia adopted the goal of being the greenest city in the world by 2020 and a fully renewable city by 2050. They developed an action plan and set a policy to measure all activities on a Carbon Intensity Index scale as seen in Figure 20 (building energy use, transportation, manufacturing, waste, etc.). Vancouver's policy is drawing regional and international attention and perhaps other Canadian cities will be moving toward these type of targets with the impact of driving buildings and their controls to have the most energy efficient outcomes possible.

23. According to the US Department of Energy, buildings consumed 41 percent of all energy in the US. Architecture 2030 has a good summary of building sector energy use: http://architecture2030.org/buildings_problem_why/.

24. Note: NBI is continually working to extend our research more deeply into Canada to document and verify ZNE buildings and policies. This list is only as complete as the previous limited outreach done in 2012 - 2013. Please contact us if you have an interest in this effort.

Figure 20: Vancouver, BC Timeline to Carbon Neutral[25]




NBI tracks policies and programs that incorporate ZNE – see the Reference Section for links to more on this subject.

## CONTROL TRENDS

The building industry has seen a dramatic rise of connectivity and monitoring that includes energy and equipment performance assessment. This extends well beyond the historical use of whole building monitoring and now includes discrete building systems, individual equipment and even each plug outlet. The boundary for controls is also expanding beyond the building as distributed generation (renewables or other onsite generation), demand response (controlling equipment use through price or demand signals), and onsite storage (renewable generation integrated batteries) become parts of the new bilateral transaction of energy with utilities and other providers of services.

These trends are driven in part by dramatic reduction in the costs of sensors and the rise of wireless and direct digital controls (DDC). This, in turn, is tied to trends from: the Internet of Things (IoT), original equipment manufacturer (OEM) integration of these low cost sensors, the rise of LED technologies, gains in universal communications protocols (e.g., BACnet), fault detection and diagnostics, and the widening use of computers and handheld devices for data access, management, and system control.

An additional, and significant trend is the interest and insistence of people on two contemporary topics: a) individual control and data access and b) the environmental character of their work or retail space. These interests merge in the area of controls where today's most highly desired young-tech work spaces reflect, and advertise, these features. A 'green' work space often includes control for natural ventilation, shading variations, daylight and lighting responsiveness customized at the individual light fixture (rather than a large zone), thermal control or e-communications for feedback regarding comfort, and lobby displays of the building energy and renewable status and awards.

In 2013, NBI identified the absence of information regarding the controls used in commercial buildings to help achieve low or zero energy. CABA selected NBI's proposal as a part of its Research Program and worked collaboratively with its members, NBI, and others to fund and support the project findings presented in this report.

25. Source: City of Vancouver Renewable Climate Action Team Presentation July 29, 2015.

## SECTION 3

# THE BUILDINGS AND PEOPLE

The research participants included members of design teams, as well as building operators and occupants. The Design Team survey instrument was used to collect the bulk of the research. A total of 23 building design teams and a total of six building operators were interviewed.

### THE BUILDINGS

Because this research is building-centric, interviewees were selected based on their role in designing or operating a specific ZNE building. NBI's Getting to Zero database was used as the primary information source when selecting candidate buildings. Table 2 shows the full list of buildings for which interviews were conducted. Appendix B shows the full list of all candidate buildings as delineated at the beginning of the project, including buildings for which no interviews were conducted.

Table 2: List of Participant ZNE Buildings

| Project | Location | Size Range | Building Type | Retrofit | Operator Survery Completed |
|---|---|---|---|---|---|
| 435 Indio Way | CA | 25k - 50k sf | Office | X | |
| Bullitt Foundation Cascadia Center for Sustainable Design and Construction | WA | 50k - 100k sf | Office | | X |
| Cornell NYC Tech First Academic Building | NY | over 100k sf | Education | | |
| David and Lucile Packard Foundation | CA | 25k - 50k sf | Office | | X |
| DPR Construction's San Francisco Office | CA | 10k - 25k sf | Office | X | |
| Exploratorium | CA | over 100k sf | Other | X | |
| Hanover Page Mill Building | CA | 50k - 100k sf | Office | | |
| IDeAs Z2 Office Building | CA | 5k - 10k sf | Office | X | |
| Lane Community College, Downtown Academic Center | OR | 50k - 100k sf | Education | | |
| Leslie Shao-Ming Field Station at Jasper Ridge" | CA | 5k - 10k sf | Education | | |

| Project | Location | Size Range | Building Type | Retrofit | Operator Survery Completed |
|---|---|---|---|---|---|
| Massachusetts Division of Fisheries & Wildlife Field HQ | MA | 25k - 50k sf | Office | | |
| Morphosis Architecture Studio | CA | 10k - 25k sf | Office | | |
| NREL Research Support Facility | CO | over 100k sf | Office | | X |
| Rice Fergus Miller Office & Studio | WA | 25k - 50k sf | Office | X | |
| Rocky Mountain Institute Innovation Center | CO | 10k - 25k sf | Office | | |
| Sacred Heart Schools Stevens Family Library | CA | 5k - 10k sf | Education | | X |
| San Luis National Wildlife Refuge HQ and Visitor Center | CA | 10k - 25k sf | Office | | |
| UC San Diego J Craig Venter Institute | CA | 25k - 50k sf | Other | | |
| UniverCity Childcare Centre | BC | 5k - 10k sf | Education | | |
| VanDusen Botanical Garden Visitor Centre | BC | 10k - 25k sf | Assembly | | X |
| Watsonville Water Resources Center | CA | 10k - 25k sf | Office | | |
| Wayne Aspinall Courthouse & Fed Bldg | CO | 25k - 50k sf | Courthouse | X | |
| West Berkeley Public Library | CA | 5k - 10k sf | Library | | X |

The list of candidate buildings was narrowed significantly as a result of early Steering Committee engagement. Robust discussions during the early phases of the project, among the whole Steering Committee, as well as in one-on-one meetings, allowed input from all project funders and stakeholders. The team decided to prioritize 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) due to the transferability of findings in these sectors to a wide range of buildings. Figure 21 and Figure 22 show the building types and sizes represented in the final population of buildings surveyed.

Figure 21: Building Types Surveyed

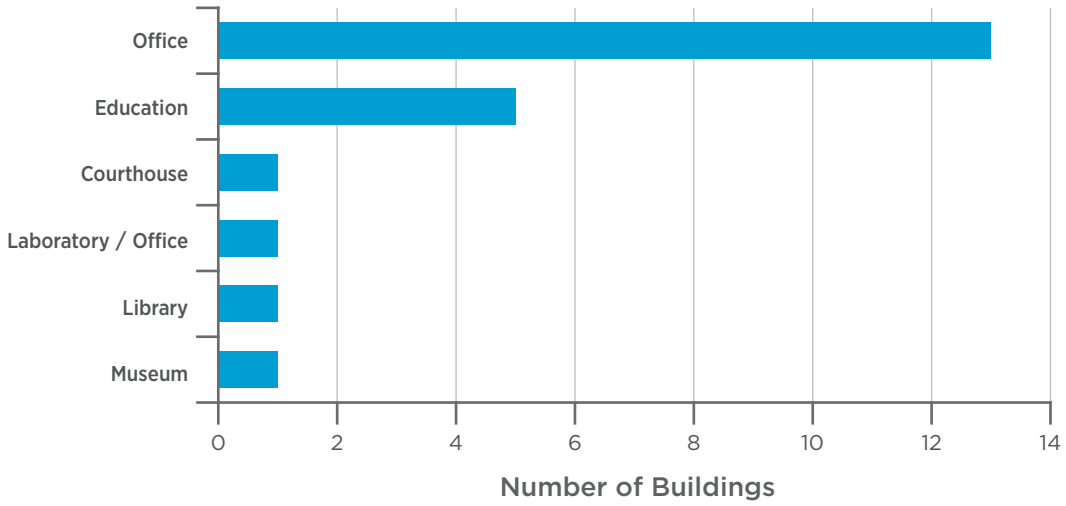
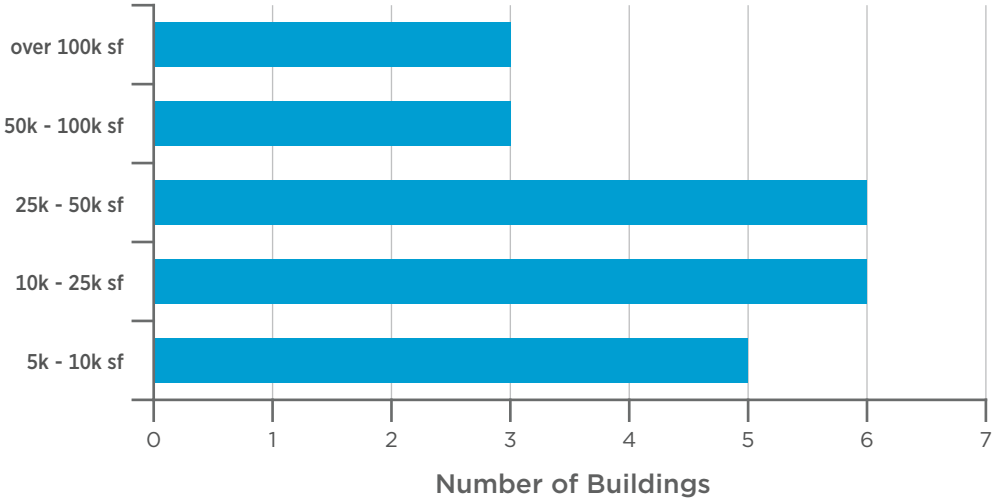



Figure 22: Size Distribution of Surveyed Buildings




## THE PEOPLE

The first section of the survey was used to determine baseline data about the respondent. This information was used to qualitatively rate the expertise or relevance of the information gathered in the rest of the survey. This allowed the responses to each survey to be evaluated based on the experience of the respondent both broadly and in specific areas.

### Design Team Survey Participants

Because of the primary role the design team interviews played in this research, it is important to gather enough information about the design team members to determine areas of knowledge and experience. One important question investigated how long the respondent has been in their current job specifically, and in this industry overall. Generally, most design team interview participants are very experienced, with an average of 11 years in the industry and more than six years in their current position. A majority (65%) of design team respondents have had training specific to designing ultra-efficient or net

zero buildings. The respondents have significant experience with designing these buildings; on average, respondents have been involved in the design or construction of four ZNE buildings during their careers.

The majority of design team survey participants (87%) frequently work on office buildings. Higher or general educational facilities are the next most common (65%). This is commensurate with the buildings surveyed: 57 percent were offices and 22 percent were higher or general education.

One common problem among designers is the lack of a feedback mechanism from operations back to designers. That is, it is relatively uncommon for the parties involved in design (architects, engineers, etc.) to keep tabs on the building performance after occupancy. However, the designers of these buildings bucked that trend, with 87 percent reporting that they have data on the building's energy performance and if it has achieved ZNE status. This is an encouraging finding: the designers of the most efficient buildings are tracking the performance of their buildings, not just handing over the keys and walking away. Figure 23 shows the measured performance feedback gap that many of these design teams have avoided. A more ideal approach to ZNE achievement would include involving the O&M team in the design process and the design team in early operations of the building.

**Figure 23: The Building Performance Feedback Gap.**

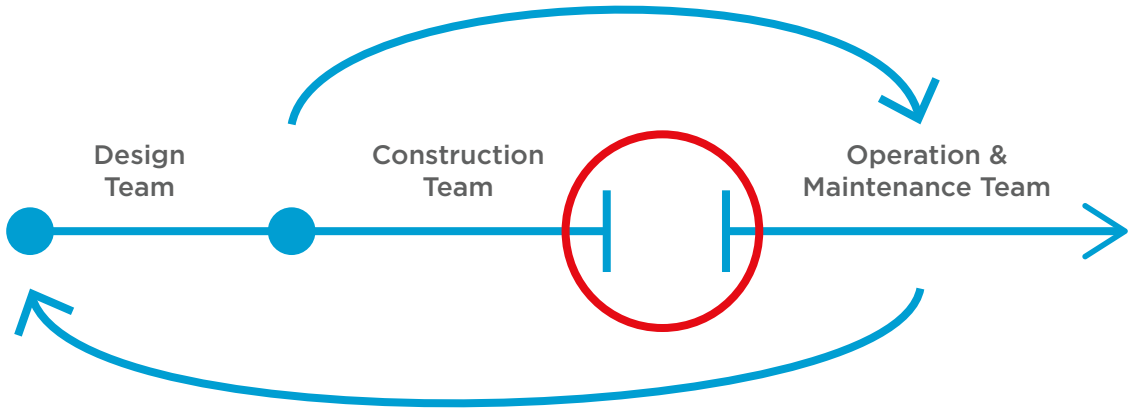



Image Credit: Ralph DiNola

## Operator Survey Participants

The research team surveyed six building operators that were selected based on a recommendation from a member of the design team, research team and Steering Committee. These individuals represented a range of building operation and management scenarios – two operated municipally owned buildings and therefore were city employees. The remaining four buildings were privately owned and developed with three operators being employed directly by the company or organization and one being employed by a third-party property management firm. In at least two of these cases, the building in question was part of a larger campus of buildings with the operator being responsible for additional buildings on that campus.

The survey focused on their current roles and responsibilities as well as their perspective on the attributes of the control systems in the buildings that they operate. While the survey did not ask for information on their professional backgrounds or experience, it was clear that there is not a common professional development path to becoming a zero net energy building operator. One respondent shared that he had previously been a project manager at a major bookstore retailer, and another spoke extensively about pulling from his background in working with highly controlled environments at a major biotechnology corporation.

### Occupant Survey Participants

In contrast to the interview method used for design teams and operators, building occupants were surveyed exclusively via an online survey platform. A total of 130 building occupants were surveyed in seven ZNE and high-performance buildings.

## SUMMARY

The following characterizations apply to the research participants:

- The buildings studied are all derived from NBI's *North America Getting to Zero Database* and represent buildings striving for ZNE performance.
- The study set of 23 buildings are primarily 10,000 – 100,000+ square feet and composed of offices and higher education buildings. A courthouse, two laboratories, a library and a museum as well as a few buildings of smaller size are also represented.
- Although the majority of buildings in the study are located in California (CA) due to the high concentration of ZNE buildings located there, the full set of buildings represents a wide range of climates.
- The individual participants within the design firms have extensive experience in the two primary building types (office and higher education) and with ZNE buildings (an average of four previous buildings each).
- Contrary to standard practice, these designers set energy targets and maintain ongoing tracking and feedback on post-occupancy energy use and operations.

## SECTION 4

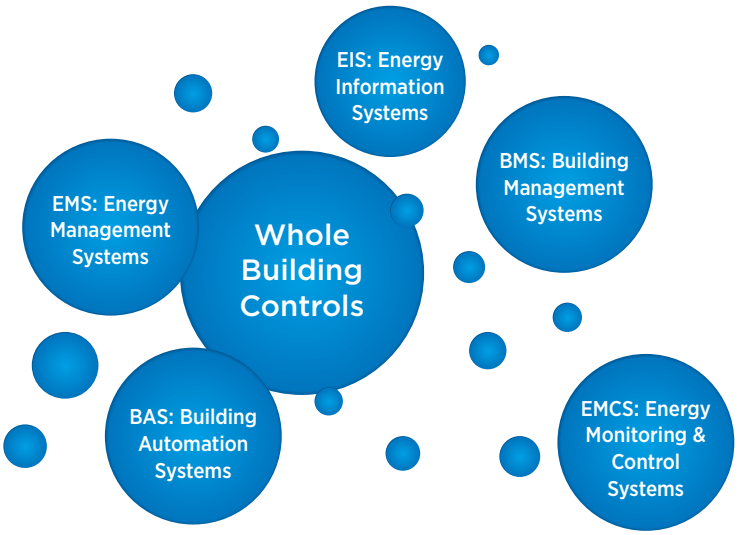
# TYPES OF CONTROLS

Building controls are systems that connect one or more pieces of equipment in a building to a user interface that assists with manual or automatic control of that equipment. In complex buildings, control systems can be highly intricate, integrating hundreds or thousands of pieces of building operations equipment and possibly security systems with a web of interactive sensors connected by wired and/or wireless technology. Smart control software uses preset and customized algorithms to optimize building systems and equipment and provide operators and occupants a window into the performance of the building, allowing for interaction and engagement in building monitoring and improved performance. As you will see through the results of this study, the controls industry is evolving rapidly and a close look at controls in ZNE buildings provides valuable insights into the opportunities for this important element of high performance buildings.

The buildings in this project used a wide variety of controls technologies and strategies. Some buildings used primarily passive heating, cooling, or lighting systems; other buildings used primarily active (e.g., mechanical) systems. However, every building (ZNE or not) relies on controls to operate properly. In every case the design team respondents said that building control strategies are either very important or critical to ensuring a net zero energy outcome. One of the primary goals of this project is to characterize the controls technology and strategies used in ZNE buildings.

The controls used in the building are of course dependent on what systems are used in the building. One of the seven sections of the Design Team Survey was dedicated to gathering information about building characteristics; another section was devoted to characterizing the controls equipment in place. The characterization of building controls was broken into a framework from whole-building level to specific end-uses. There is a wide variety of approaches to whole building controls: Building Automation Systems (BAS), Environmental (or Energy) Monitoring Systems (EMS), Energy Information Systems (EIS), and more. Each of these terms means something different and may have somewhat different meanings to different people. This project mainly attempted to characterize the extent of the whole-building controls architecture in terms of the end-uses subject to automated central control. Figure 24 shows some of the most common system types within the constellation of whole-building controls systems.

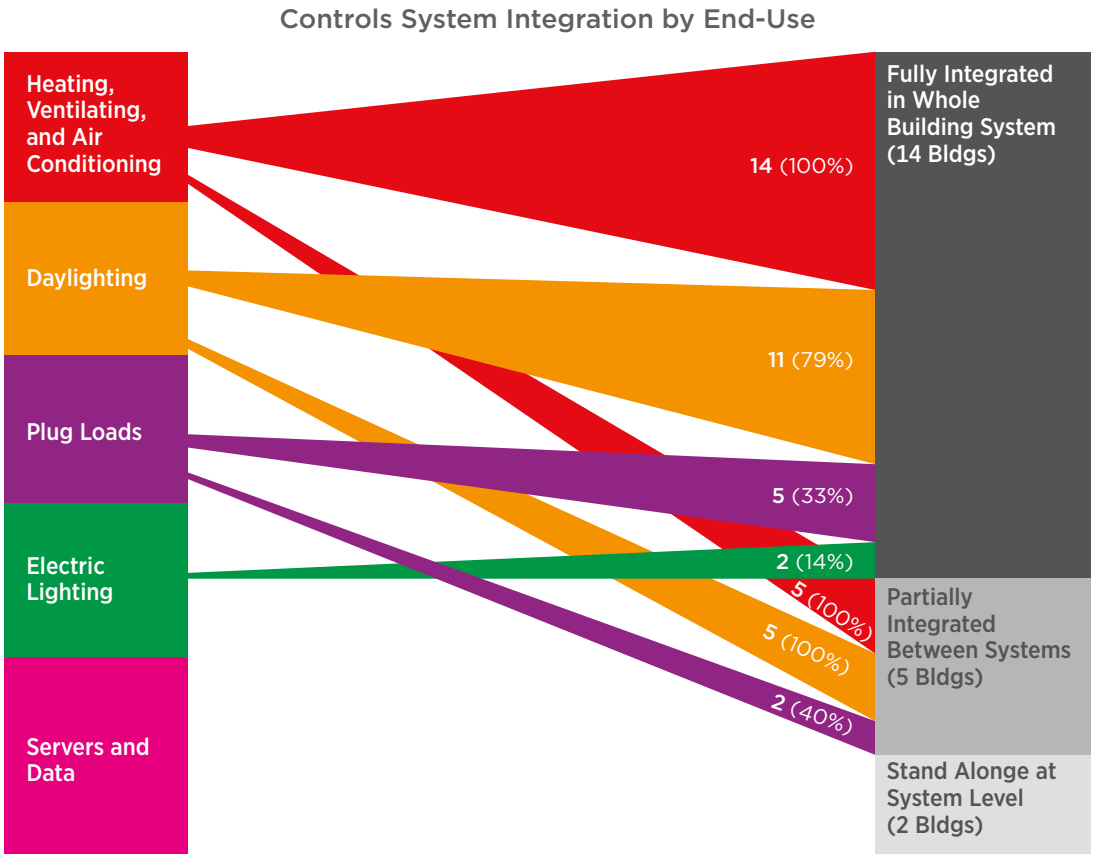
Figure 24: The Constellation of Whole Building Controls Systems




## WHOLE BUILDING CONTROLS AND INTEGRATION

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. Just as the pilot of a modern aircraft relies on the flight computer to help fly the plane, the operator of a modern building needs a reliable and intelligent controls system so that the building can perform at the highest levels. Figure 25 shows the distribution of controls integration strategies.

Figure 25: Extent of End-Use Controls Integration

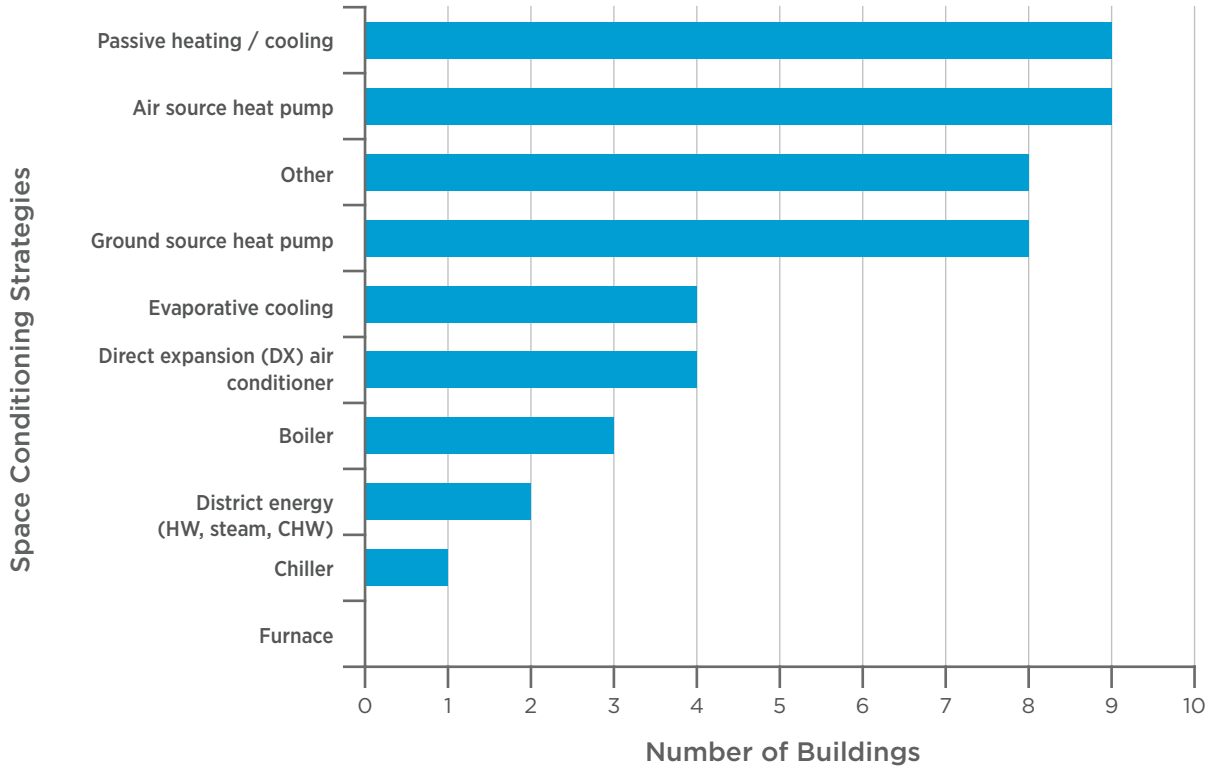



Despite the preponderance of integrated controls, the controls sequences are not everything: fully 74 percent of the buildings surveyed rely on the occupant for some part of the success of the controls operations. The highest-performing buildings have engaged operators and occupants standing on the shoulders of intelligent and integrated controls systems.

## HVAC

Most buildings surveyed used an active system as their primary source of heating and cooling. Nine buildings, or 39 percent of those surveyed, used passive heating and cooling as the primary means of providing space conditioning. Figure 26 shows the primary space conditioning strategies used in the buildings surveyed. Some buildings use multiple strategies, for example, passive heating with backup provided by air source heat pumps. Figure 26 also shows 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 (74 percent use heat pumps).

Figure 26: Primary Space Conditioning Strategies

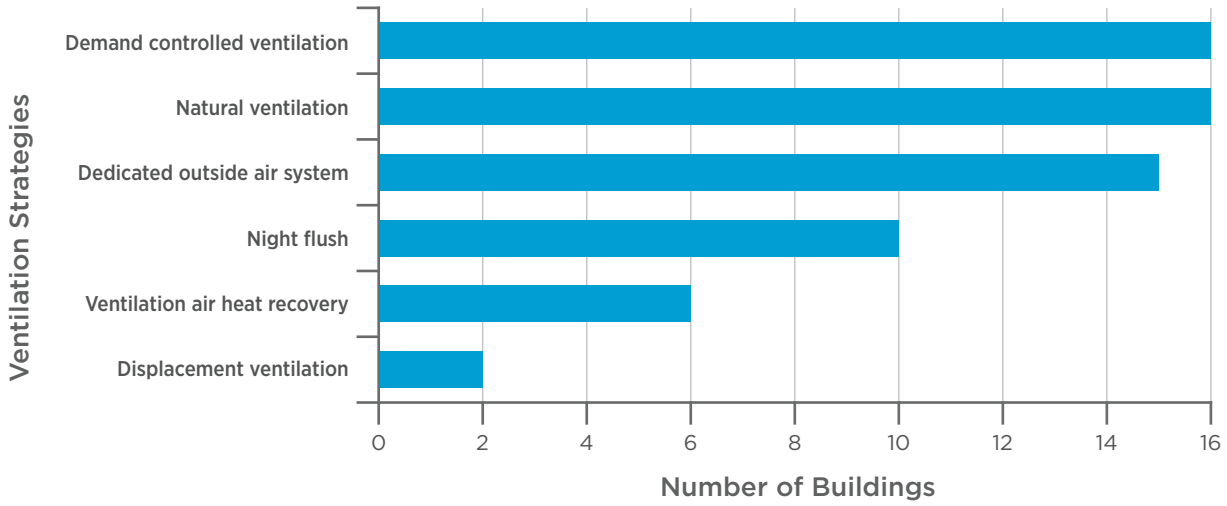



Natural ventilation is a very common strategy in ZNE buildings and among high-performance buildings in general. Many buildings used multiple innovative ventilation strategies simultaneously. For example, some buildings used natural ventilation during the day (in some cases with mechanized windows or large-scale systems such as the Monodraught, 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 systems to precondition entering outside air 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.

Figure 27: Ventilation Strategies




At least five buildings give occupants direct control over fans. Also, at least five buildings allow occupants to open windows or otherwise control the natural ventilation system. The Massachusetts Department of Fish and Wildlife Headquarters Building Management System centrally monitors all windows and overrides zonal HVAC programmed operations when windows are manually opened. A different building's designer noted that such a strategy would have been helpful and lamented their building's lack of this control capability:

> "I don't like having any sort of fan system able to operate without motorized windows to shut the fan off if the windows are opened."

One creative strategy, applied in the 435 Indio building, was to allow occupants to override the automated windows via a smartphone app created by the controls sub-contractor. The Rocky Mountain Innovation Center provides chairs with electric heat and an integrated fan to give occupants more control over their personal temperature.[26]

## Radiant Systems

An additional part of the survey addressed the HVAC distribution system and demonstrates another unique aspect of ZNE buildings: they are not proponents of fan energy loads due to the high energy demand of moving air through duct work and noise. Within this dataset 64 percent of the buildings used radiant systems (52 percent used radiant heating; 35 percent used radiant cooling) to meet thermal comfort needs coupled with a Dedicated Outdoor Air System (DOAS) to address ventilation needs. The radiant systems are controlled primarily by the air temperature (43%) with slab temperature being the second most selected control approach (26%). With the growth of these systems and their role in helping get to zero energy, more information on the characteristics, energy impact, and performance of radiant controls would be helpful. The heat pump and radiant system trends match data in NBI's larger data set of ZNE buildings.

## Shading, Daylighting, and Glare Control

Daylighting is a critical component in allowing ZNE buildings to reach their design goals. Only two buildings did not select daylighting as a feature. 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 percent of those were automated or a combination of automated and manual (Figure 29). In several cases the project was unable to add either exterior or interior shading due to spatial, historic, or other design constraints. Figure 28 and Figure 29 show the strategies used for shading and glare control.

26. The Hyperchair, co-developed by Peter Rumsey and UC Berkeley's Center for the Built Environment; see http://www.rmi.org/rmi_innovation_center for more information.

Figure 28: Exterior Shading Strategies

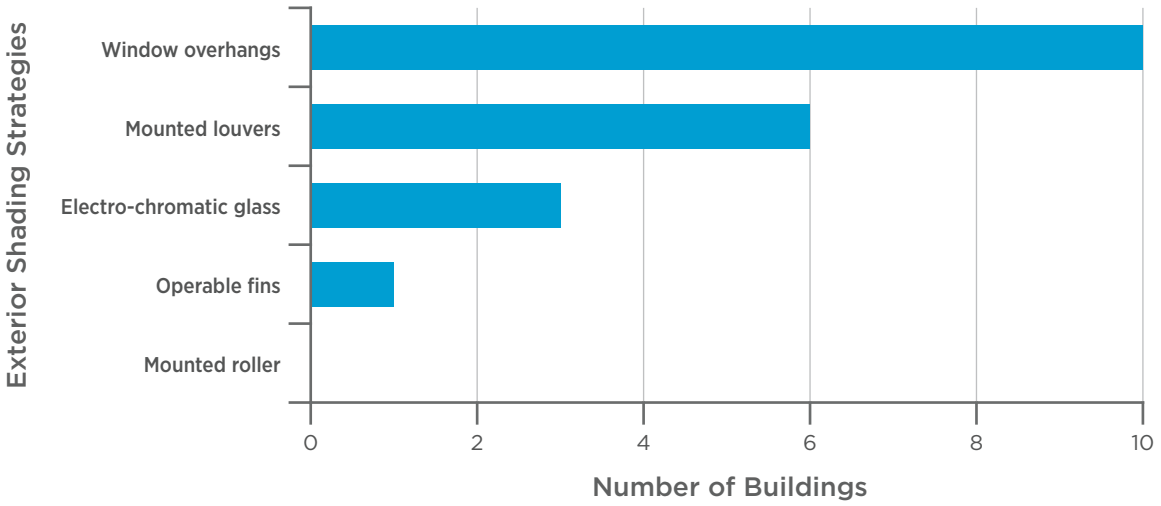
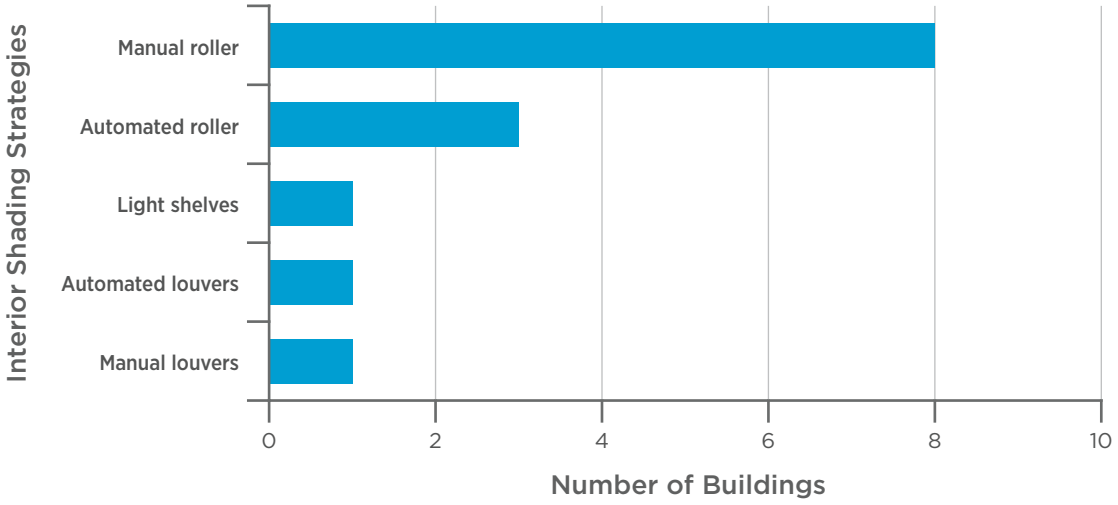



Figure 29: Interior Shading Strategies




While fixed architectural devices (overhangs and louvers) were the most common exterior shading strategy, three buildings used electro-chromatic glass. These buildings noted that the use of this glass was able to significantly reduce the HVAC needs for the space. One building designer noted:

> "We used electro-chromatic glass for two large skylights that drastically reduced the HVAC load in the zones nearby."

Even within specific categories, buildings used varying strategies for controlling daylight and managing glare. Of the five buildings that use automated shading devices, four stated that they made that design decision in large part for thermal controllability. Energy savings was also important, with three buildings noting that as a major driver in their choice to automate shading control. One building noted that first cost was important and another noted that because the interior shades are located in skylights they had to be automated. Other drivers, such as ease of use, previous experience, light pollution, and bird strike mitigation, did not enter into the decision making process.

## Electric Lighting

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 stands in opposition to 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 most common (60% of buildings) though stepped dimming was also common (35% of buildings). Only one building reported not using any dimming controls whatsoever.

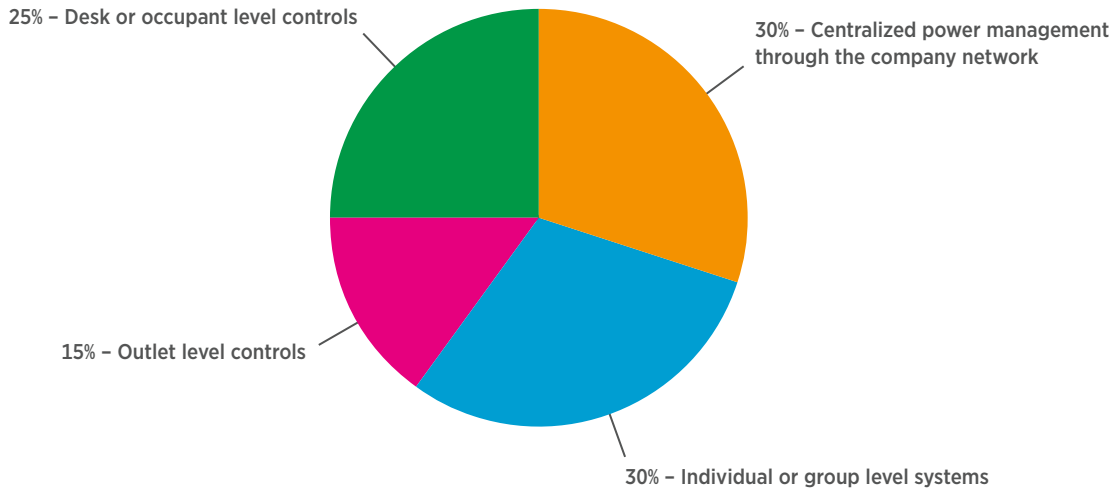
The majority of buildings used wired controls for their electric lighting. However, 29 percent of buildings reported used wireless controls (typically, some areas use wireless lighting controls and others use wired lighting controls). Luminaire-level lighting controls – which are controllable at each 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 and that we should anticipate more of these fixture-level controls.

## Plug Loads and Server Rooms

As HVAC, lighting, and other loads are reduced through design, technology and codes, plug loads are responsible for a larger percentage of the building load and therefore becoming more and more important. In some high performance and ZNE buildings plug loads can account for more than half of the total electricity consumed in the building. However, because plug loads are widely distributed throughout the building and are generally not regulated by energy codes, reducing their energy use is challenging. One strategy used with significant success in the American National Renewable Laboratory's Research Support Facility is to set up each work station with a smart power strip that must be turned on every morning. Once turned on, the strip will provide power for 11 hours. This approach, in which the system is off by default, is a promising way to reduce the energy used when equipment is idle.

The majority of buildings surveyed (64%) use some kind of plug load controls or monitoring. Of these buildings, the strategies employed vary from the centralized to the localized, as shown in Figure 30.

Figure 30: Plug Load Control and Monitoring Strategies




Some buildings also struggle to manage the energy load from server rooms and information technology (IT) equipment. For example, the Wayne Aspinall Courthouse and Federal Building houses multiple government agencies, each with their own dedicated IT equipment. The designer tried to get all these agencies to co-locate their servers in a common space

in the basement, with security mesh between servers to provide physical isolation. However, the agency IT staff refused. As such, the building has eight separate server closets throughout the building, making the provision of dedicated cooling in an efficient manner more difficult. Server virtualization (a technology that enables multiple server operations to be consolidated onto one piece of hardware) has provided some savings. In two cases, building occupants have considered moving some computing operations to the cloud to reduce building energy consumption. At least one building (the Rocky Mountain Institute Innovation Center) was able to harvest waste heat from the server room to provide free heat to other spaces during winter.

### Direct Current and Low Voltage Strategies

Several buildings (28%) considered direct current (DC) plug load equipment or microgrid strategies. These strategies were generally considered as an energy savings measure (reducing the energy wasted by conversion from direct current, as produced by a photovoltaic system, to alternating current (AC) for distribution, and then back to DC at the device level). In general these strategies were considered but significant hurdles emerged to their implementation. For example, in one case, because different equipment runs at different DC voltages the additional electronic converters would eliminate the advantage of using DC. This suggests that standardization of DC devices would likely help smooth the path for wider adoption of this technology.

## SUMMARY

- In every case the design team respondents said that building control strategies are either very important or critical to ensuring a ZNE outcome.
- Most (67%) buildings reported using an integrated whole-building controls system to address all major end-uses. Only a few (9%) have no whole-building controls architecture (these buildings have controls only at the end-use level). HVAC was included in all buildings with fully or partially integrated whole-building controls systems; daylighting was included in most of these systems.
- Most buildings surveyed used a combination of automated and manual controls to adjust the building's environment. The best of these found ways to integrate the manual and automated controls (e.g., when occupants manually open windows, this will automatically override the HVAC zonal programming until the window is shut).
- Light switches are still far more prevalent than occupancy sensors, but intelligent light switches are becoming more common. Some buildings have switches whose default setting is "off" and are programmed so that that the lights must be manually turned on, and will eventually turn themselves back off when not in use.
- Daylighting controls are an integral part of high performance buildings; glare control and shading must be done properly to realize the benefits of daylighting. Most designers used fixed elements (overhangs, louvers) or manual roller shades. Thermal controllability and energy savings were the main drivers causing designers to select automated shading systems.
- Managing plug loads is challenging in all buildings; in high performance buildings with highly efficient major systems (HVAC, lighting, etc.) this challenge is more apparent. Buildings have come up with a variety of customized controls solutions to address this problem, but plug load energy use remains a tough issue to address.
- Shades or blinds were used in over half of the projects (52% - 12 projects) toward their energy reduction and occupant comfort goals.

## SECTION 5

# CONTROL DESIGN SELECTION PROCESS

The second portion of the survey tackled the control design and selection process associated with 21 projects.[27] Based on feedback from this section it is clear that designing a ZNE building involves rigid execution of the design intent, thorough documentation, specifications and detailed sequence of operations, while still allowing for a great deal of built-in flexibility when it comes to implementation, and ultimately, building operation. While this survey demonstrated that there are plenty of commonalities in approaches to achieving a ZNE goal, it also demonstrated that how one ultimately implements a ZNE design is built on experience and approaches can vary.

### PROJECT OBJECTIVES

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. Eighteen of the surveyed projects had a stated energy goal of zero net energy, two had a goal of zero net electric and one was designed to be "zero net energy ready" (Table 3).

Table 3: Energy Goals Indicated by Project

| 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 | ■ | ■ | | | ■ | | |

27. Two projects did not fill out the second section of our survey which addressed the control selection process. For this reason our total participants for this section is 21.

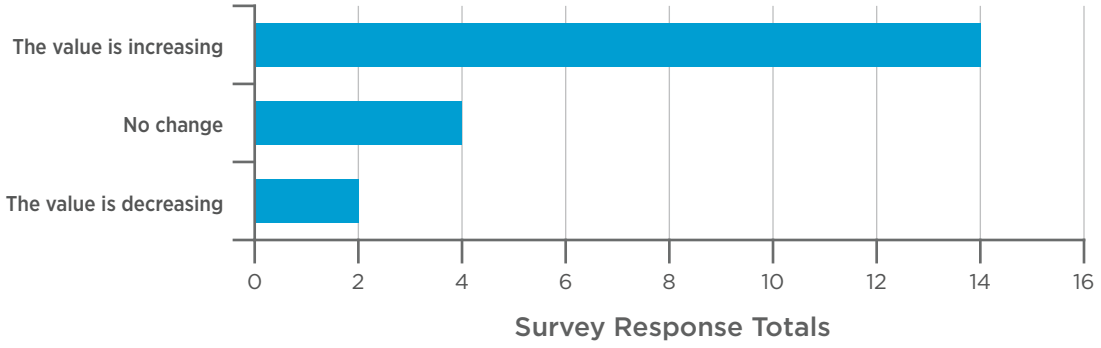
| Building ID | Zero Net Energy | LEED Certified | Living Building Challenge | Zero Net Electric | Carbon Neutral | Architecture 2030 Compliant | Zero Net Energy Ready |
|---|---|---|---|---|---|---|---|
| M | ■ | ■ | | | | ■ | |
| N | ■ | | ■ | | | ■ | |
| O | ■ | ■ | ■ | | | | |
| P | ■ | | | ■ | | | |
| R | ■ | ■ | | ■ | ■ | ■ | |
| S | ■ | | ■ | ■ | | | |
| T | ■ | ■ | ■ | | | | |
| U | | ■ | | ■ | | | |
| V | ■ | | | | | | |
| W | ■ | | | | | | |

While a majority of the projects targeted a zero net energy goal, a number of projects identified multiple energy goals that were in alignment with this goal of achieving ZNE. Nine of the 21 projects (40%) included in this survey used the ZNE goal as a spring board for three or more energy goals, including LEED and Living Building certification.

The motivations for these goals commonly included wanting to do "the right" thing and "leading by example." Usually this meant the ownership or organization was motivated to take a leadership position on environmental issues and the design team advocating for one or more of the specific energy goals. Two of the projects indicated that the net zero energy goal was the result of a state, provincial, or governmental agency pilot program.

When asked about the value controls systems provide to zero net energy buildings, 14 participants felt that the value was increasing while only two felt the value was decreasing (Figure 31).

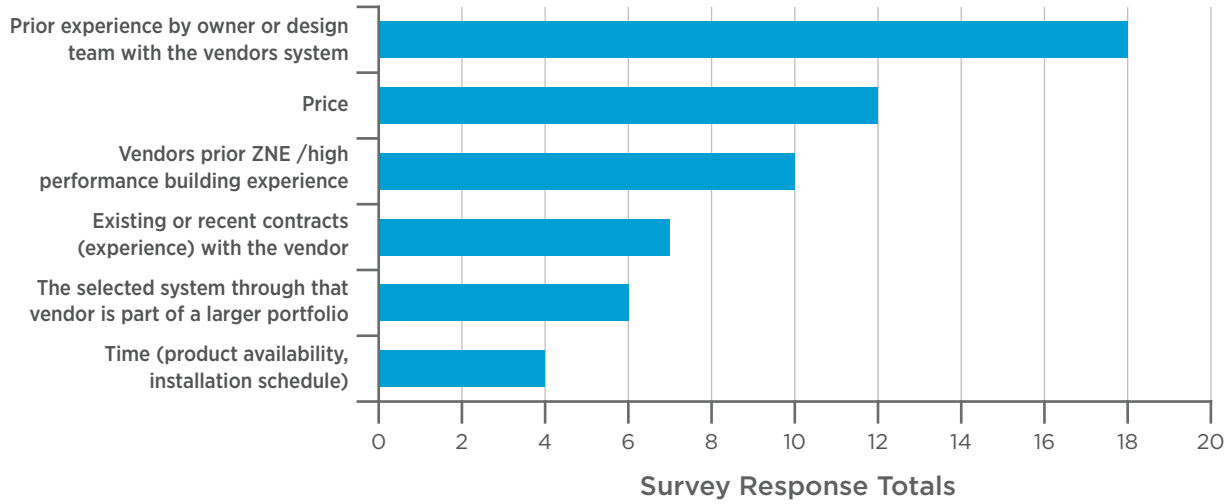
Figure 31: Value of Investing in Controls System



## SELECTION CRITERIA

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%) rely on prior experience with the vendors system as the top criterion when it comes to selecting a vendor (Figure 32).

Figure 32: Criteria for Selecting a Controls Vendor/Subcontractor




The fact that this criterion was selected more frequently than cost demonstrates the important role that controls play in achieving a ZNE goal where the working relationship with the vendor or their system takes precedence.

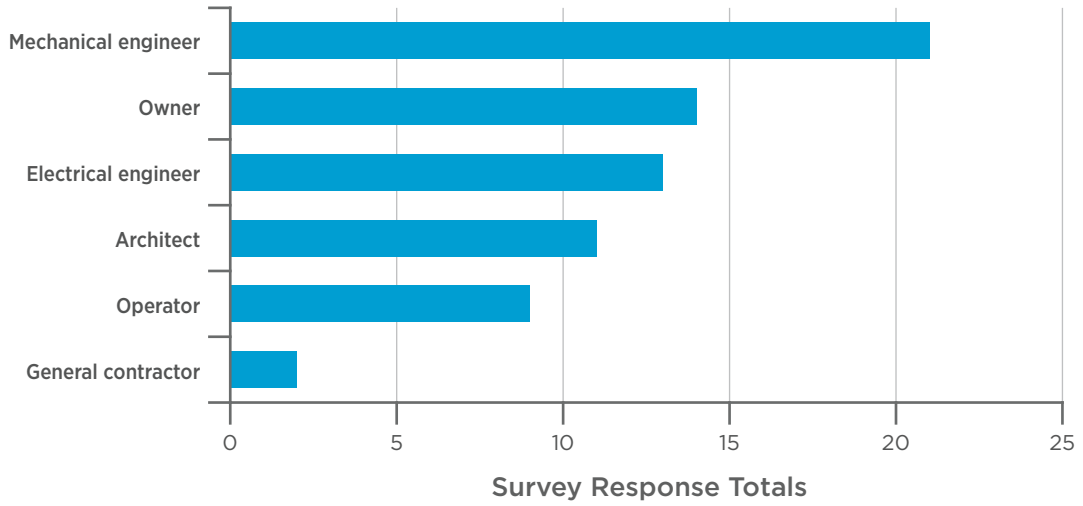
### Roles in Selection Process

The engineer of record (EOR) was the responsible party 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 due to the larger scope associated with designing the heating, cooling and ventilation systems. It was these people who interfaced with the owner and pulled the subcontractors into the process as needed.

In the role of EOR, they were 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 half of all the projects surveyed.

In about half of the buildings, this process included the building operator (Figure 33). However, when asked who ideally should be involved in this early design and selection process, more than half of the remaining designers indicated that the building operator should have been involved. This sentiment was echoed by the six building operators that were surveyed for this project and is further addressed in Section 6.

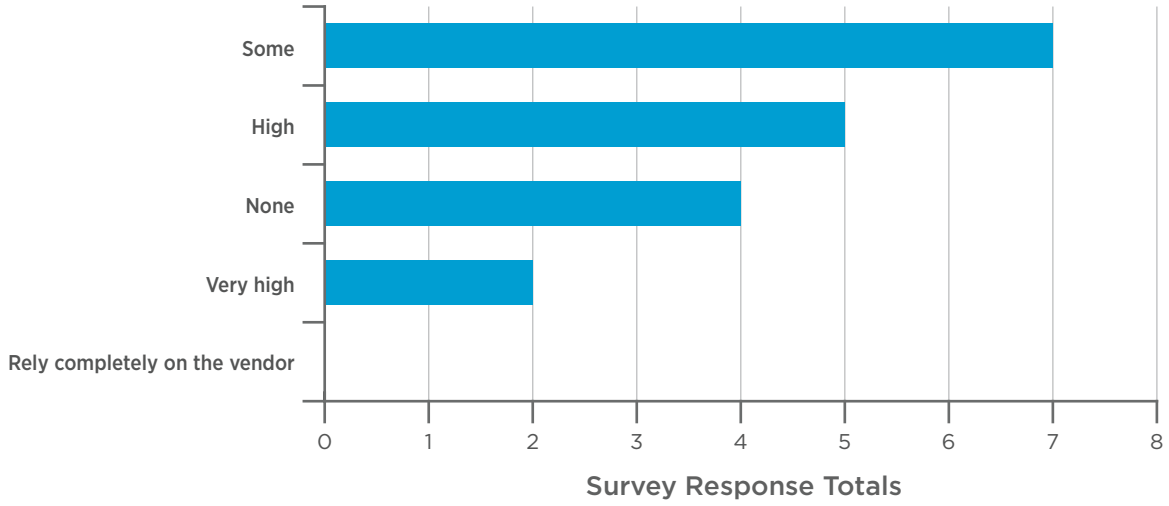
Figure 33: Parties involved in the early design and selection process for controls




## Basis for Selection of Controls and Firms

As previously noted, when it comes to selecting a controls vendor or subcontractor, prior experience was the primary driver for most firms that were surveyed and was considered more important than cost – which was the second most selected criterion. While most designers felt that this rapport was important to their vendor selection process, as seen in in Figure 34, the influence that these vendors have on what controls systems get selected is somewhat marginal. Only about half of the respondents felt that the vendor's prior experience with ZNE/high performance buildings was a top criterion.

Figure 34: Level of influence vendors have on the control selection process

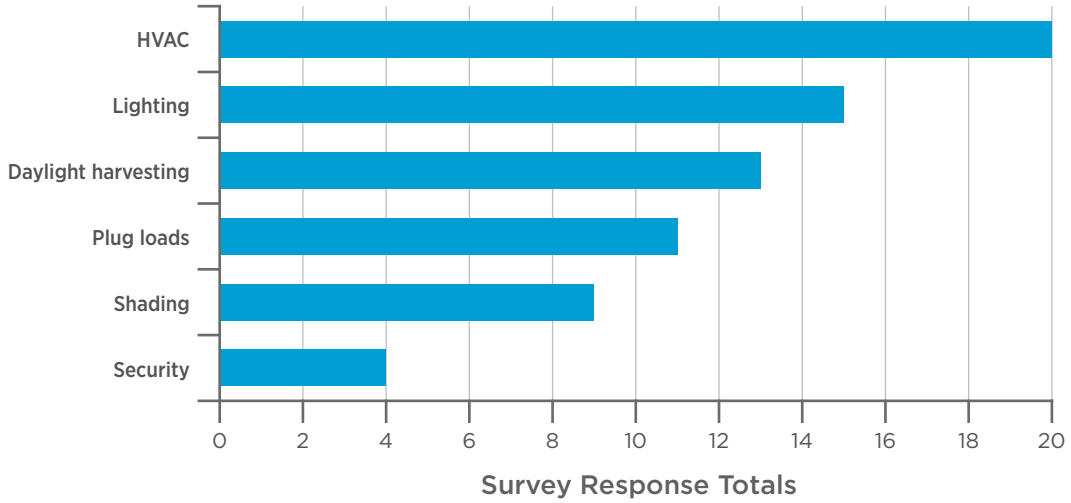



A number of the designers highlighted the important role the sequence of operations plays in this relationship with the vendor and the commissioning agent. Not only is it critical to provide them with a complete and detailed sequence of operations as early as possible, but it is also important to maintain that relationship with the control vendor once the building is occupied.

## Key Control Attributes

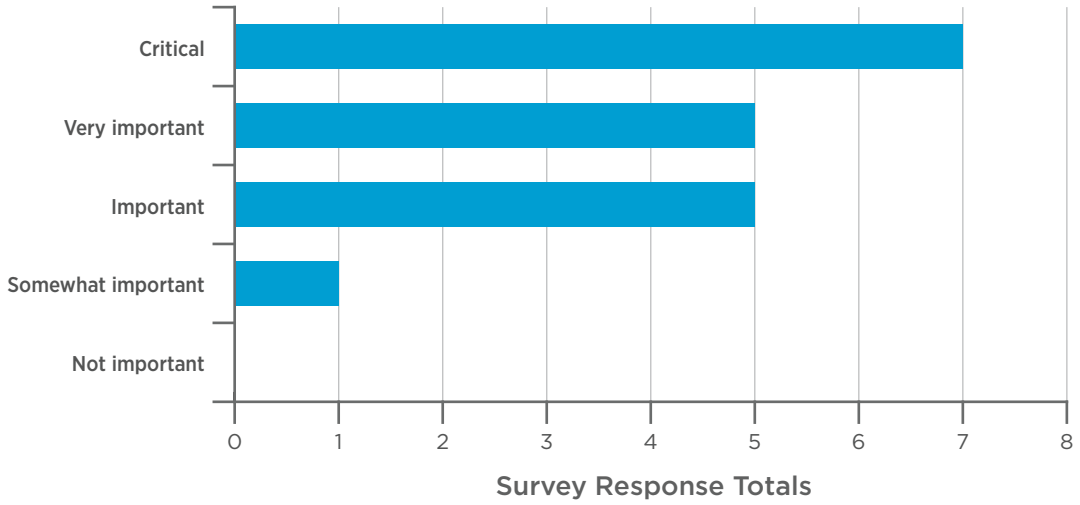
The primary control attributes addressed in the survey included system integration, automation functionality, and the end-user experience, including the user interface and preference settings. When it came to integrating end-uses within a whole building controls system, a majority of the designers (12) surveyed indicated that conflicting communication protocols did not limit their options for control strategies. As noted in Figure 35, almost all of those surveyed felt that the HVAC system needed to be able to be integrated with a whole building controls system while lighting, daylight harvesting and plug loads represented the second tier of preferences for integration.

Figure 35: Integration of systems with a whole building controls system




Regarding the role of the user interface when it came to selecting a particular controls system, the survey respondents were generally split on how important the user interface was in that selection process; with half saying it did influence their selection process. However, this was not the case when it came to indicating how important the attributes of the user interface and preference setting where in ensuring proper use by the building operator. Almost all the respondents to this question felt that it was important or critical.

Figure 36: Importance of user interface and preference settings in ensuring proper operation



When asked for two to three considerations when it came to system automation, numerous designers felt it was important to keep the automation functionality simple and to select devices that can be turned off automatically. The other consideration is whether the building has a dedicated facility person, as this can allow a more sophisticated approach to automation.

## SYSTEM COMMUNICATIONS AND DATA ACCESS

Several questions within the survey addressed communication protocols used by the controls systems. A majority of the respondents indicated that communication protocols did not limit their control options on the design side, despite the fact the controls system using propriety protocols were used in at least nine of the projects surveyed. As seen in Table 4, a mix of open source and proprietary systems represented the seven projects that felt they were limited by conflicting communication protocols.

Table 4: Impact of Varying Communication Protocols

| | Did conflicting communications protocols limit your options for control strategies? | | What best describes the communications protocol implemented in your project? | |
|---|---|---|---|---|
| Building ID | Yes | No | Open | Proprietary |
| A | | ■ | | ■ |
| B | | ■ | ■ | |
| D | ■ | | ■ | |
| E | | | | |
| F | ■ | | | ■ |
| G | ■ | | | ■ |
| H | | ■ | | |
| I | | ■ | | ■ |
| J | | ■ | | |
| K | | ■ | ■ | |
| L | ■ | | ■ | |
| M | | ■ | | |
| N | | ■ | | ■ |
| O | | ■ | | |
| P | ■ | | | ■ |
| R | ■ | | ■ | |
| S | | ■ | | ■ |
| T | | | | ■ |

| | Did conflicting communications protocols limit your options for control strategies? | | What best describes the communications protocol implemented in your project? | |
|---|---|---|---|---|
| Building ID | Yes | No | Open | Proprietary |
| U | | | | |
| V | ■ | | ■ | ■ |
| W | | ■ | ■ | |

However, when asked why their building required greater follow up, 'control integration' issues were selected by nine participants and were second only to 'incorrect installation.' Table 5 looks at the nine projects that claimed to have integration issues in the field to see if there was any correspondence to the type of communication protocols (open versus proprietary) used in those projects. The controls systems in five of these projects were characterized as using open source communication protocols, while three were characterized as being proprietary. One project indicated it had a 'mix of both.' While this is a limited sample size, it does not appear that choosing a controls system that uses open source communication protocols results in fewer integration issues in the field.

Table 5: Types of Communication Protocols Found in Projects with Control Integration Issues

| | What best describes the communications protocol implemented in your project? | |
|---|---|---|
| Building ID | Open | Proprietary |
| F | | ■ |
| H | | |
| K | ■ | |
| L | ■ | |
| R | ■ | |
| S | | ■ |
| U | | |
| V | ■ | ■ |
| W | ■ | |

Of the nine projects that claimed to have controls integration issues, several indicated that they had a difficult time integrating the controls for their variable refrigerant flow (VRF) systems into the building management system (BMS).

A vast majority of the designers (19) felt that cybersecurity did not play a role in their selection process.

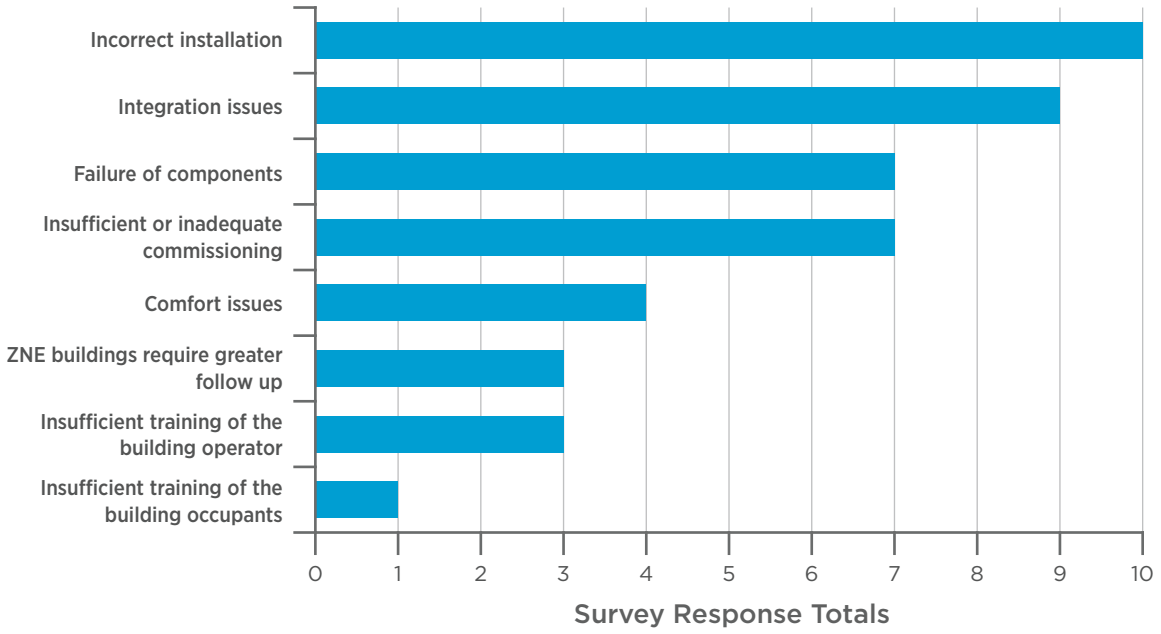
## SUMMARY

The second portion of the survey conducted for this project offered some valuable insight into how designer teams view controls systems and what some of the attributes they are looking for in these systems. Here are the key takeaways from this section:

- Early identification and communication of energy goals was critical to the design and selection process of the controls.

- Selection of the controls typically falls to the engineer of record, with some input from the building owner and an assortment of subcontractors.
- A vast majority (86%) selected prior experience with the vendors system is a top criteria, ahead of 57 percent that chose price.
- Most (66%) of respondents say that the attributes of the user interface and preference setting were very important or critical to ensuring proper use by the operator.
- The use of open source versus proprietary communication protocols does not appear to limit the selection process for building controls, nor does the use of open source protocols mitigate integration issues in the field.
- Despite the focus on performance and the qualification of the design and construction teams associated with these projects, incorrect installation of controls systems in the field is the greatest reason for excessive follow-up, followed by integration issues (Figure 37).

Figure 37: Reasons for Greater Follow-up by Design Team than Anticipated



# SECTION 6

# USER EXPERIENCE

## OPERATORS

Due to the critical role that building operators play in the performance of net zero energy buildings, it was important to survey and obtain the perspective of a number of the operators who interact with these buildings and their controls on a regular basis. Of the 23 buildings that participated in various portions of the design surveys, the research team surveyed the operators of six of these buildings.

Only one of the six building operators surveyed was involved in the design phase of the building they were tasked with operating. All of the building operators agreed that the building handoff and startup phase would have been smoother had they been involved in the design phase of the project. As noted by one of the operators, the facility managers or building operators should ideally be involved in the building control selection and specification process because 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 responses from these operators are a strong indicator for the important role that building controls play in zero net energy buildings. Five of the six surveyed agreed that the value of investing in controls for these buildings is increasing. Similarly, four of the six agreed that a building designed with numerous passive systems did not reduce the scope of controls needed to effectively operate the building.

### Roles and Responsibilities

As previously mentioned, the building operators that were interviewed represented a range of building operation and management scenarios – out of six buildings, two were municipally owned buildings and the operators were city employees. The remaining four buildings were privately owned and developed. Three operators were employed directly by the company or organization that owned the building and one operator was employed by a third-party property management firm. In at least two cases, the building in question was part of a larger campus of buildings, with the operator being responsible for additional buildings on that campus.

In their roles as building operators, these individuals are responsible for ensuring that the building is running in an optimal way, meeting the stated goals of the owner and ensuring that occupants are satisfied with their indoor environments. Their responsibilities not only include monitoring and proper operation of all HVAC, lighting and electrical systems, but can also include plumbing and wastewater systems. Three of the operators specifically mentioned challenges associated with managing and troubleshooting the controls associated with gray or black water systems.

Table 6: Building Monitoring Responsibility

| Building ID | Onsite Facility Manager or Engineer | Third party | Owner | Architect/ Engineer | Software-As-Service (SAS) |
|---|---|---|---|---|---|
| B | ■ | ■ | ■ | ■ | |
| J | ■ | | ■ | | |
| K | ■ | | | | |
| O | ■ | ■ | | ■ | |
| T | ■ | | | | |
| W | ■ | ■ | ■ | | |

As shown in Table 6, all six operators surveyed were directly monitoring their buildings in some capacity. In three cases, the building operators received additional support from a third-party. For both of these parties, this monitoring served a critical role in providing data that allowed them to track the performance of their buildings, as well as provide information that can be used diagnostically to assess issues and correct them. The three building owners and two architect/engineering firms were monitoring these buildings for energy performance and benchmarking purposes, and were less focused on gathering information that could be used diagnostically.

The building operators typically worked alone and would subcontract out work if additional help was needed. However, almost all of them spoke to the critical relationship they have with the control vendor that was used on the project. This often involved assistance with adjusting or reprogramming the sequence of control operations. This is especially true within the first year of operations. One operator mentioned how important it was to have the vendor's phone number on speed dial when he was brought on to operate the building.

Additionally, the building operator needs to understand the design intent behind some of the systems in order to explain why the lights might be off or the need to dress appropriate to the season given the expanded comfort range. Four of the six surveyed operators said they handled occupant comfort complaint resolution differently in their building than they might in a conventional building.

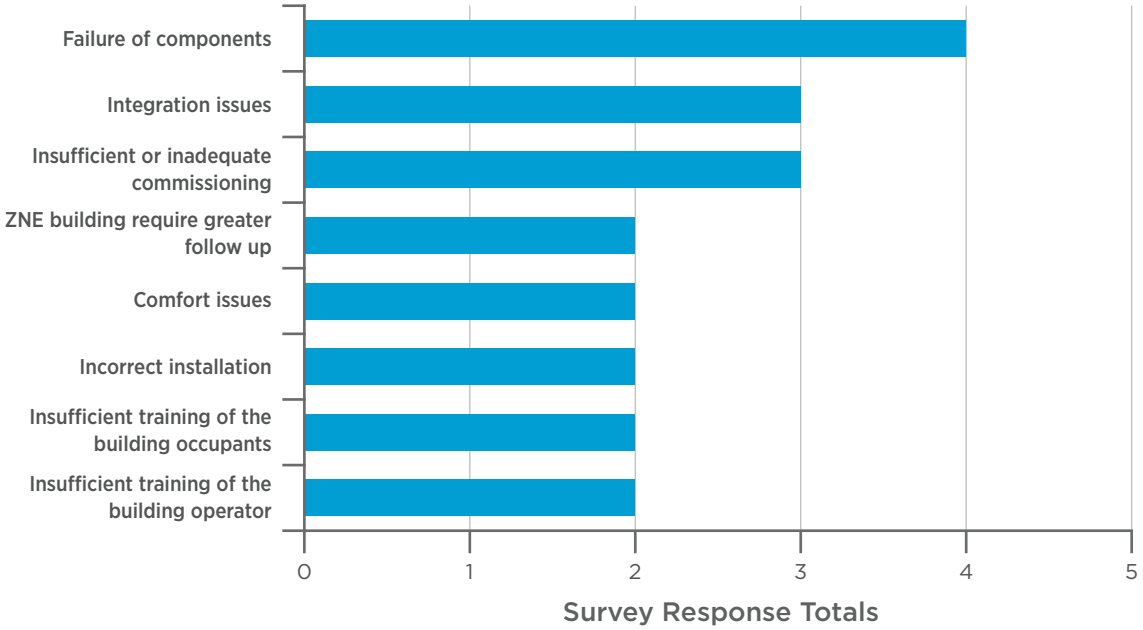
## Training and Experience

When asked about what training the building operators received on the specific system featured in these buildings, almost all of them spoke about how a majority of the training for them occurred on the job. Each building has its own particularities and it invariably takes time and experience to become familiar with how these buildings behave in response to different control approaches and settings. However, even though almost all of the operators characterized their training as being on-the-ground, essential to this process was having access to the operations and maintenance (O&M) manuals, the commissioning agent and the final commissioning report. All six of the buildings in question were commissioned.

In the instances when formal training was provided, it was provided through the control vendor, and in one case training was used to obtain LEED credits. Two of the operators surveyed referenced the value in videotaping any of the training provided so that they can be available for future use.

When asked why they had to follow up with the design team, the operators surveyed felt that inadequate training was on a lower tier of issues compared to failure of components, integration issues and insufficient or inadequate commissioning (Figure 38).

Figure 38: Reasons for Operator Follow-up with the Design Team




An additional item that came out of this survey with the building operators was the importance of putting together a System Support or Procedure Manual. This manual not only allows for a smoother transition if there is a change in staff, but also serves as a quick reference guide in case the building operator is temporarily unavailable or on vacation. One building operator also mentioned how helpful it was to be provided with a "Configuration Item List" that allows him to quickly identify and order replacement parts or components. This list was a deliverable that was provided by the contractor.

## Observations and Challenges

Through our discussions with these six building operators, it was evident that they took great pride in the work that they do with these buildings and that the ZNE status was a demonstration of their skill sets. Several of them spoke about the importance of getting to know the particular characteristics of these buildings by installing various sensors to monitor a variety of points such as slab and space temperatures and pressure differentials. Monitoring these points allows them to tinker with the best control approaches to optimizing the different systems. Taking these buildings from startup to steady state operations can be very challenging and speaks to the importance of investing in the building operator.

There were several additional items that came up through the course of the survey that are worth observing, including some of the challenges associated with operating these buildings.

- The lack of air diffusers in one of the radiant conditioned buildings has resulted in fewer temperature complaints from occupants, which is different from buildings that rely on air distribution for space conditioning.
- The daylighting in the libraries needs to be explained, as people expect electrical lights to be on in these spaces despite availability of adequate light levels – this was perceived by the operators as a learning opportunity to explain some of the buildings' features.
- In one of the radiant conditioned buildings, the building operator felt that there was not enough space in the mechanical room given the presence of all the pipes and pumps. This challenge was characterized by other operators as the need to consider the ease of access and usage when designing these buildings and systems.
- Almost all of the operators mentioned mislabeled pipes, incorrect metering and conflicting communication protocols.
- Three building operators spoke specifically about challenges associated with operating gray or black water systems. While these types of systems were not addressed in the scope of the research, they clearly require a portion of the operators' time and attention.

## OCCUPANTS

Building occupants play an essential role in determining the energy outcome of a building. A 2011 Sensitivity Analysis report determined that: "a significant percentage of building energy use is driven directly by operational and occupant habits that are completely independent of building design, and in many cases these post-design characteristics can have a larger impact on total energy use than variations in the design of the building itself." When asked about this, 55 percent of the building occupants surveyed felt that occupants play a strong or very major role in helping to control building systems that impact the energy use of the building. For this reason, it was essential to get the occupant perspective and feedback on the controls systems featured in ZNE and High Performance Buildings. Through a brief survey consisting of 10 questions, 130 occupants provided feedback on seven buildings, sharing their level of interaction and satisfaction with the control systems featured in their buildings.

These occupants were highly aware of the ZNE goals of their buildings (90%), yet there was a surprising finding regarding their exposure to regular communications (emails, bulletins, etc.) to help support those goals. The design team survey said occupant engagement through signage and continued outreach was critical and represented it as an integrated part of these buildings, however, nearly 70 percent of the occupant respondents said they do not receive any communication on the topic of their role in reducing energy consumption in their building. This further displays a gap from design intent to operations and occupancy shown in the diagram of Figure 23.

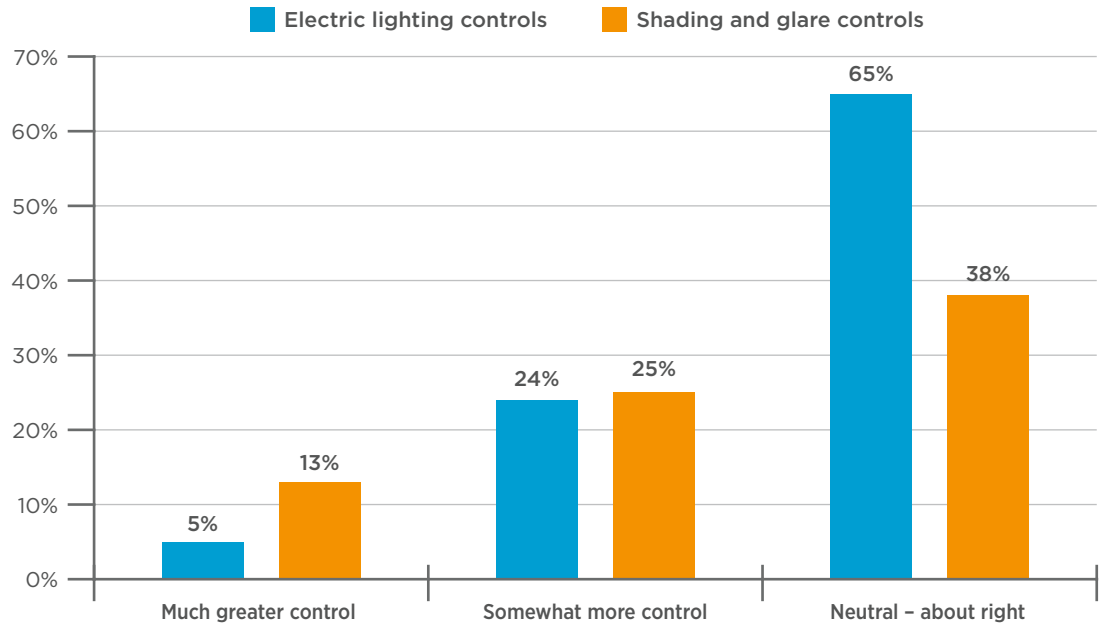
### Controls Interaction and Satisfaction

The occupant survey sought to gauge what end uses the occupants had access to, and whether they wanted more or less controllability of that end use, as well as their level of satisfaction with the building systems and their characteristics. In addition, the survey sought to determine what role occupants should play in controlling systems that impact the energy use of buildings, and their perspective on the level of automation afforded by the building control systems. As captured in the sections below, for the most part these buildings provide highly comfortable work environments featuring strong satisfaction with the ample daylighting and high quality indoor air.

### Lighting and Daylighting

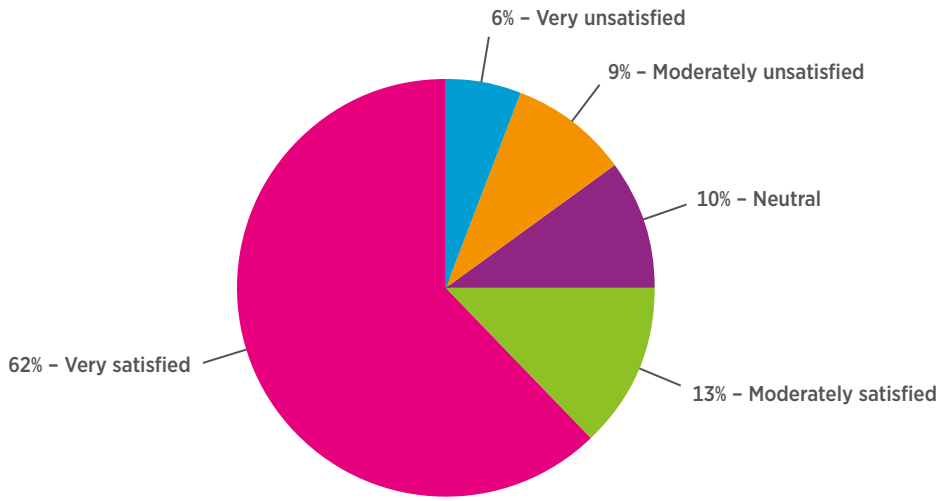
Almost all occupants indicated that they had some ability to control the electrical lighting in their space. In Figure 39, a clear majority (65%) of respondents were satisfied with their ability to control their electrical lighting while 38 percent felt the same about their ability to control for shading and glare. This seems to indicate that the electrical lighting control systems featured in these buildings are for the most part being used as designed. They offer satisfactory levels of interaction and controllability, while some additional attention to shading and glare control options would further improve occupant comfort levels in some of these buildings.

Figure 39: Occupant Interest in Interaction with Lighting and Shade Controls




The level of satisfaction with the lighting and daylighting, regardless of control access, was quite high in these buildings, with 70 percent in the moderate to very satisfied category with its characteristics. With regard to daylighting, a noteworthy 75 percent of occupants indicated that they were moderately or very satisfied with the daylighting system and characteristics (Figure 40).

Figure 40: Satisfaction with Daylighting System and Characteristics



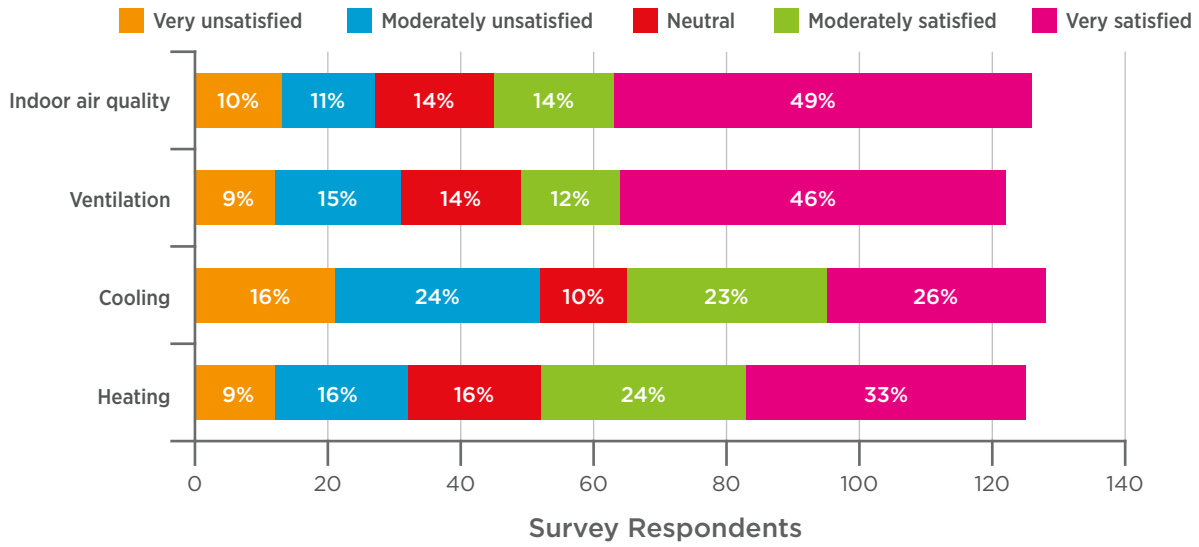

## Heating, Cooling and Ventilation

The control of space temperature has been a point of contention for as long as humans have occupied buildings. The occupants of these study buildings are no different, with half of them indicating that they would like greater temperature controllability. However, this was not the case for ventilation. Although 42 percent of the occupants lacked ventilation

control directly (or were unaware of control options), 58 percent of the respondents indicated that they were moderately or very satisfied with their level of ventilation controllability as shown in Figure 41.

This high level of satisfaction is reflected by the 63 percent of respondents ranging from moderate to very satisfied with the indoor air quality, as shown in Figure 41. The heating system characteristics also seemed to be successful, with 57 percent of survey respondents indicating moderate to high levels of satisfaction. The cooling system scored less satisfactorily, with respondents almost split between satisfied responses (49%) and unsatisfied (40%) (Figure 41). This simple survey uncovered some 'hot spots' from occupants. Some respondents that were unsatisfied with cooling provided strong commentary regarding high temperatures, incorrect default settings and generally excessively hot work conditions. There is clearly an issue at a few of the projects, which included comments regarding operational and automated windows being highly variable and out of sync with the thermal demands of the space or causing excess noise when in open-mode. There were others that noted that they loved the fresh air and experienced less illness in an office that is not strictly sealed and air-conditioned. A few comments included lack of responsiveness from shade automation.

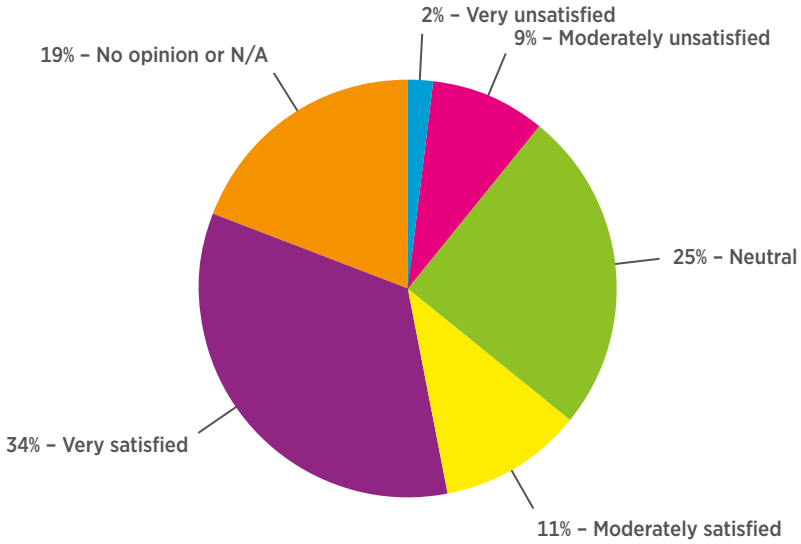
Figure 41: Satisfaction with HVAC Systems and Characteristics




## Plug Loads

Plug loads play a critical role in achieving ZNE performance, and the need to control them is essential to any project on the path to zero. As stated by one of the respondents: *"since we have the other systems so well honed, the plug load measurement and controls seem to be exceptionally important."* For this reason, and also considering the absence of plug load controls in typical code level buildings, getting the occupant perspective on interaction and satisfaction with plug load control approaches was an important objective under study. Despite the relative 'newness' of the presence of plug load controls in these buildings, 70 percent indicated that they were either neutral or satisfied with the plug controls (Figure 42).

Figure 42: Satisfaction with Plug Load Control Systems




## SUMMARY

**Operator**. While we have seen the market for ZNE continue to grow, the building industry still has a long way to go in order to formally acknowledge the role that the building operator plays in determining the success of a project, and in providing them with the tools they need in order to see greater market penetration of ZNE buildings. Below is the summary from the building operator surveys:

- The future building operator should be brought into the design process as early as possible, and should be involved in all sequence of operations development efforts as well as the commissioning process. Not only will this facilitate a smoother startup process, but will also allow the operator to understand the design intent behind the key strategies and systems.
- The building operator's 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 is important, there was not a consistent approach to formal training that these operators had gone through, nor was there a common professional development path that led them to their current position. Most of the training was characterized as happening informally on-the-ground, with a heavy reliance on the Operations and Maintenance (O&M) Manual and the commissioning process and report.
- The building operator is responsible for compiling a System Support or Procedure Manual, which is important to ensuring the persistence of efficient operations and ensuring that the project is meeting its performance goals.

**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. Given the energy performance goals of these projects and the feedback provided by the occupants surveyed, it appears that the design teams and building operators have for the most part successfully walked the line between automation and reliance on the building occupants to interact with the systems in providing healthy and comfortable interior environments. Below is the summary of the occupant surveys:

- Occupants are very satisfied with the quality of light in their spaces, with 65 percent indicating that the felt like they had about the right level of access, and ability to, control their electric lighting.

- In providing ample daylighting and views, it is also important to allow occupants to have the ability to control shading elements in response to glare.
- The level of satisfaction with the lighting and daylighting, regardless of control access, was quite high in these buildings, with 70 percent in the moderate to very satisfied category with its characteristics. With regard to daylighting, a noteworthy 75 percent of occupants indicated that they were moderately or very satisfied with the daylighting system and characteristics.
- Occupants responded favorably to the ventilation strategies featured in these buildings, including natural ventilation and dedicated outdoor air systems.
- The heating systems and strategies appeared to be well regarded, while more occupants expressed a desire to more finely control cooling in their zones.
- The plug load controls don't appear to be problematic or obtrusive for most of the building occupants.

## SECTION 7

# ENERGY FINDINGS

The drivers for incorporating controls usually begin with meeting needs for equipment management, ease of operations, system reliability, increasing occupant comfort and meeting design conditions, with energy management and savings as an additional benefit.

Today's energy use is widely included in building codes, utility programs and, increasingly, as a critical part of building project objectives. The ability to identify the specific energy relationship attributed to a single technology or system is compelling but remains challenging. Unlike a lighting fixture, computer or the HVAC system, the controls by themselves are not an end-use that is distinctly measureable. Rather, they support, enhance, integrate and compliment the systems and/or the whole building.

In this study, NBI sought quantitative and qualitative information on controls in low and zero net energy buildings. NBI asked design teams to identify the energy use and contributions of various controlled systems to the building energy target and their inclusion (or exclusion) of occupants from the energy control strategies. This section presents the energy findings from the: 1) buildings, 2) systems and 3) role of occupants.

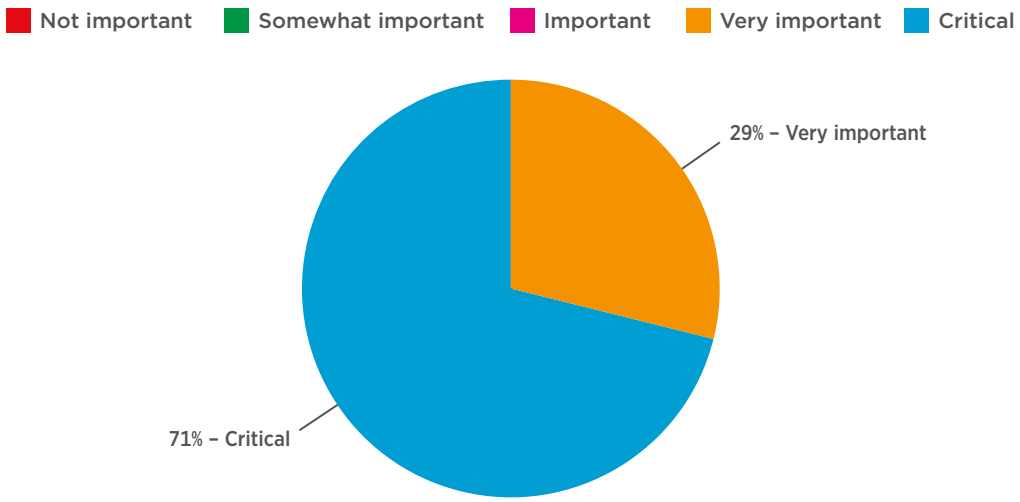
### BUILDINGS: GETTING TO ZERO

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 with each building (and monitored performance feedback), the path to zero is refined and becomes their new standard practice.

#### Target Setting and Modeling

**Energy Targets**. Setting an absolute energy target (rather than the typical 'percent better than') very early in the design planning was seen as one of the most fundamental parts of delivering a low or zero energy building. All respondents identified setting energy targets as very important or critical to the design process and outcomes (Figure 43).

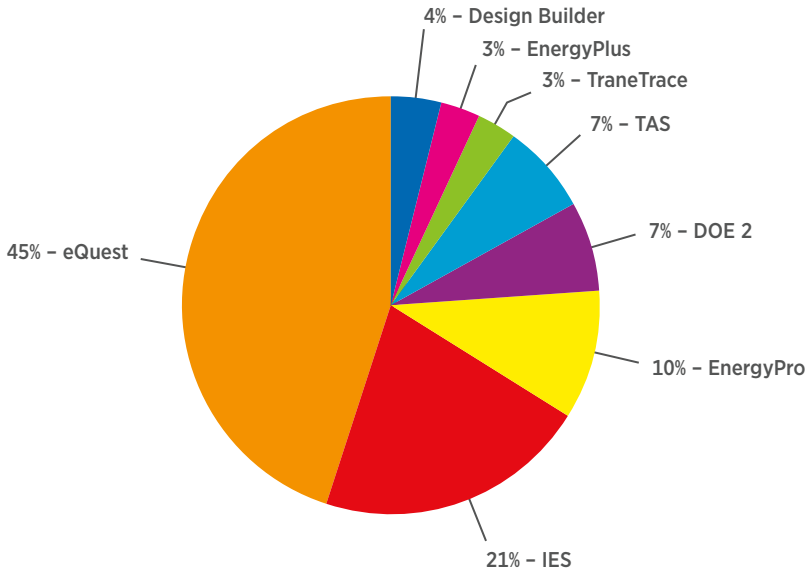
Figure 43: Responses on the Value of Setting Energy Targets




**Modeling**. The projects primarily used a High Performance or a LEED building as the baseline with only 30 percent identifying code as their baseline. A range of energy modeling software was then used to estimate savings and compare the impact of design strategies and technologies. Most firms utilized more than one software. For radiant heating/cooling systems and natural ventilation, Integrated Environmental Solutions (IES) and Thermal Analysis Simulation (TAS) software provided improved analysis over standard building energy software. Integrating newer system types and passive strategies to software is recognized as a current modeling gap. The US Department of Energy (DOE) is working to expand capabilities to model newer system types (e.g., dedicated outdoor air systems (DOAS), variable refrigerant flow (VRF), displacement ventilation) using EnergyPlus.[29]

The energy software eQuest was by far the most frequently utilized (45% of the responses). This is likely because the software is free and has historically been the dominant energy software for LEED submissions (Figure 44).[30]

Figure 44: Energy Modeling Software - Frequency of Use

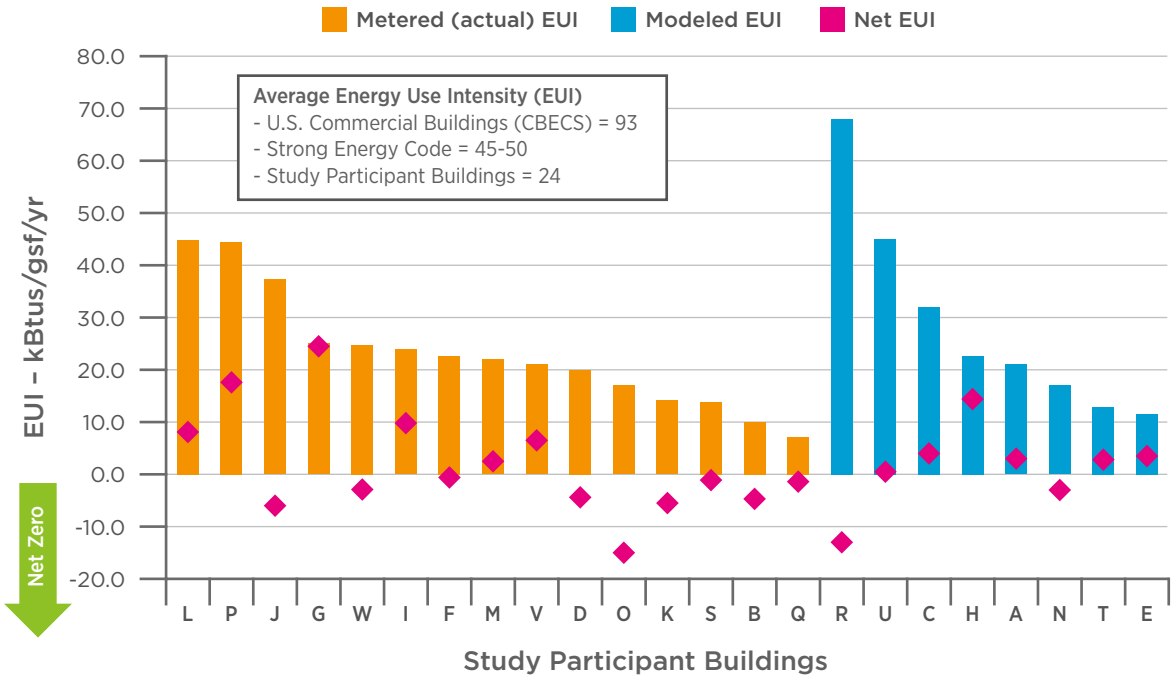



29. M. Witte; US DOE 2014; http://energy.gov/sites/prod/files/2014/08/f18/emt01_Witte_042214.pdf.
30. U.S. Green Building Council's LEED program requires energy information, but does not require or promote the use of any specific modeling software.

### Modeled and Measured Energy Use

Zero net energy buildings use energy, but to get to 'net' zero they must have energy use so low that onsite renewables can supply 100 percent or more of the building's energy use over a year, resulting in a net use of zero. A commercial building designed to zero net energy typically uses 25 percent or less (75% reduction) of the energy of a standard existing building of the same type and size, or approximately half that of a building built to strong energy code levels.[31] The projects in this study reflect the very best energy use targets, and in some cases metered data has shown that they have surpassed those targets. As shown in Figure 45, the mix of modeled estimates of Energy Use Intensity (EUI) versus metered results is approximately 60/40 respectively.[32] These buildings collectively have targets and outcomes with an average EUI of just 22 kBtu/sf/yr, and that drops to an EUI of just 19 kBtu/sf/yr when the two lab buildings are not in the average.

Figure 45: Energy Use Intensity (EUI) of Participant Buildings




Overall, finalizing building commissioning, ongoing monitoring and data quality control affect a project's ability to meet targets. However, unlike most buildings in the U.S., these buildings have specific energy targets and intentions for ongoing monitoring and performance feedback. This cycle of information helps with the assessment and refinements to identify areas that are not performing as designed and dial down the energy use. It should be noted that not all buildings that target zero net energy will reach that outcome, but the design and ongoing effort usually result in exemplary performance. Next, the study drilled into estimates of the system contribution to these low energy outcomes.

## SYSTEMS: CONTROLLING THE PATH TO ZERO

As shown in Section 2 (Participant Buildings), the surveyed buildings include large buildings as well as colder climate zones. Designing first for passive strategies and then controlling the system-level energy use, including unregulated loads such as plug loads and occupant behaviors, is a key factor to getting to these very low energy use numbers.

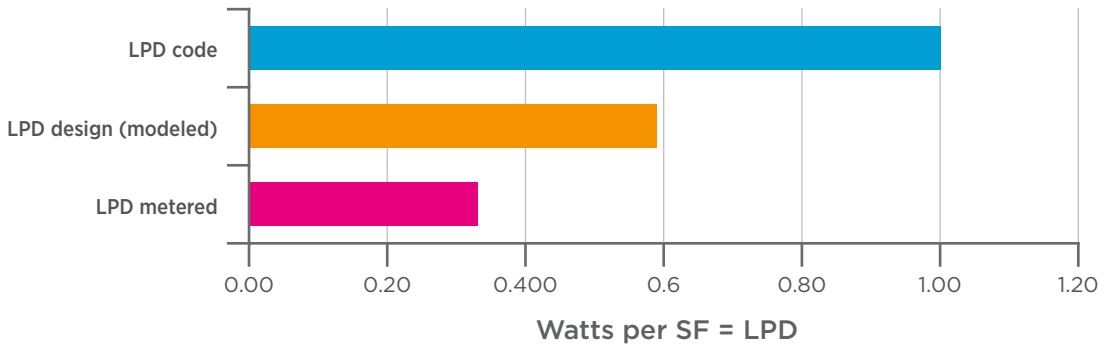
31. There is a wide range of energy codes in the U.S. with the strongest energy codes (IECC 2013, IgCC, Title 24 California) resulting in code buildings that are very energy efficient. These codes are also on paths to get to zero energy standards over the next decade.
32. Energy Use Intensity (EUI) is a metric of whole building energy use expressed in kBtu/sf/yr.

## Beating Baselines

Like the whole building EUI numbers, the system-level energy targets are well below standard design practice. The survey participants had breakouts for system-level baselines for lighting and plug loads.

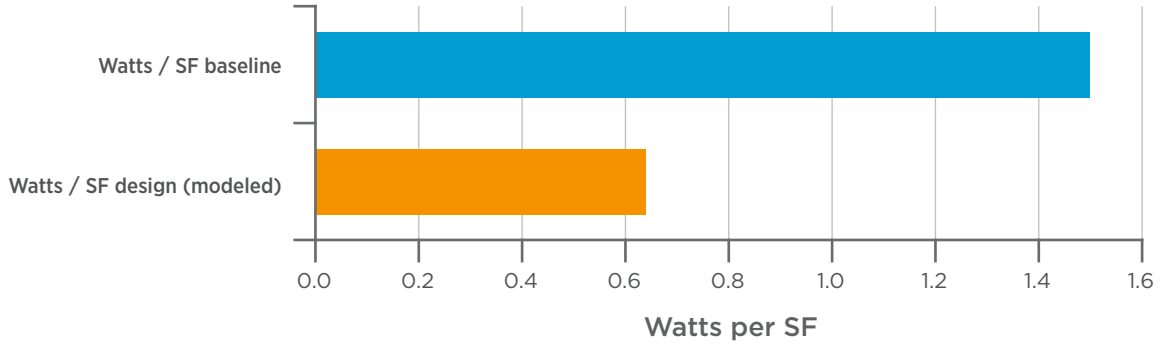
**Lighting**. Lighting has long been the first line of controls for energy management. While switching, time clocks, daylight and occupancy dimming are code in some jurisdictions, they remain foundational control strategies to reduce and eliminate electric lighting when not needed. Layered on these controls, the survey buildings have footprints, envelopes and even interior design strategies such as low partitions and light coloring that optimize the opportunity for maximum daylight, thus minimal electric light. Buildings have also employed LED task lamps and controls at the luminaire level, creating a deeper savings strategy resulting in the lighting watts per square foot – called Lighting Power Density (LPD) – to be 40-60 percent less than code (Figure 46).

Figure 46: Lighting Power Densities for Participant Buildings




**Plug Loads**. Plug Loads are the newest of control attention and, in standard buildings, remain rarely controlled beyond on/off switches on the equipment or at power strips. Yet the energy use of plug loads is the fastest growing area of energy use and is outside the realm of most energy codes.[33] Again, lessons from these early adopters clarified that design energy targets for plug loads could be reduced by almost 60 percent compared to standard baselines (Figure 47), even with multiple personal monitors and ancillary electronics on the rise.

Figure 47: Plug Load Energy Use




## Contributing to Performance

**Lighting**. In the research survey, the questions on the energy impact of controls were developed to identify the design firm's attribution of the various controlled systems to the overall energy use reduction of the building. Lighting was usually cited as being > 15 percent of the savings and never as less than 11 percent of the overall savings, with daylighting controls as the most common reference (Figure 48).

33. Energy Information Agency 2008 Annual Energy Outlook.

**HVAC**. HVAC controls were slightly less cited than lighting, but still predominately selected as contributing >15 percent (Figure 48) of the whole building savings. For HVAC, the strategies cited were to apply passive strategies with controls for natural ventilation, night flush and thermal set point controls as the first step. As referenced in Section 2, with the trend of these buildings having a greater proportion of ground source and air source heat pumps plus radiant heating and cooling distribution systems, these high-efficiency HVAC systems controls contribute to the low-energy use of these buildings.

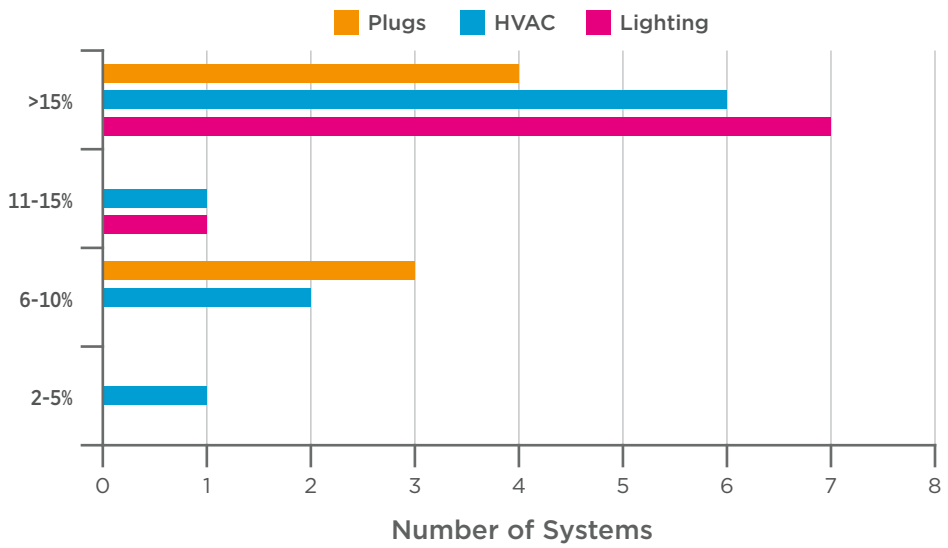
In this regard, an interesting comment from one of the participating design firms was that in testing the sensitivity of set points during energy modeling for a 150,000+ sf building:

**"A two degree change up or down from baseline (75 F cooling/70 F heating) resulted in approximately a six percent gain or penalty in the total building energy use (2 EUI for this building)."**

Plug Loads. With improved envelope, lighting and HVAC design improvements and increasing code stringency, plug loads can now represent as much as 50 percent of the total building loads.[34] Resulting analysis of the survey question "please indicate the contribution to the whole building energy savings for various controlled systems" clarified that controlling plug load energy use was recognized at either >15 percent or six to 10 percent of whole building energy savings contribution (Figure 48). The comments referenced equipment level controls, and particularly an analysis of one building represented that,

**"the integrated design for "off" as the default setting resulted in a 20 percent whole building energy savings (5-6 EUI)."**

Figure 48: Whole Building Energy Savings per Controlled System




**Exterior Shading Devices**. Shading devices are increasingly becoming a heat and glare reduction strategy and incorporating automation often coupled with manual operation options (details on the types of shading/blinds is in Section 2).

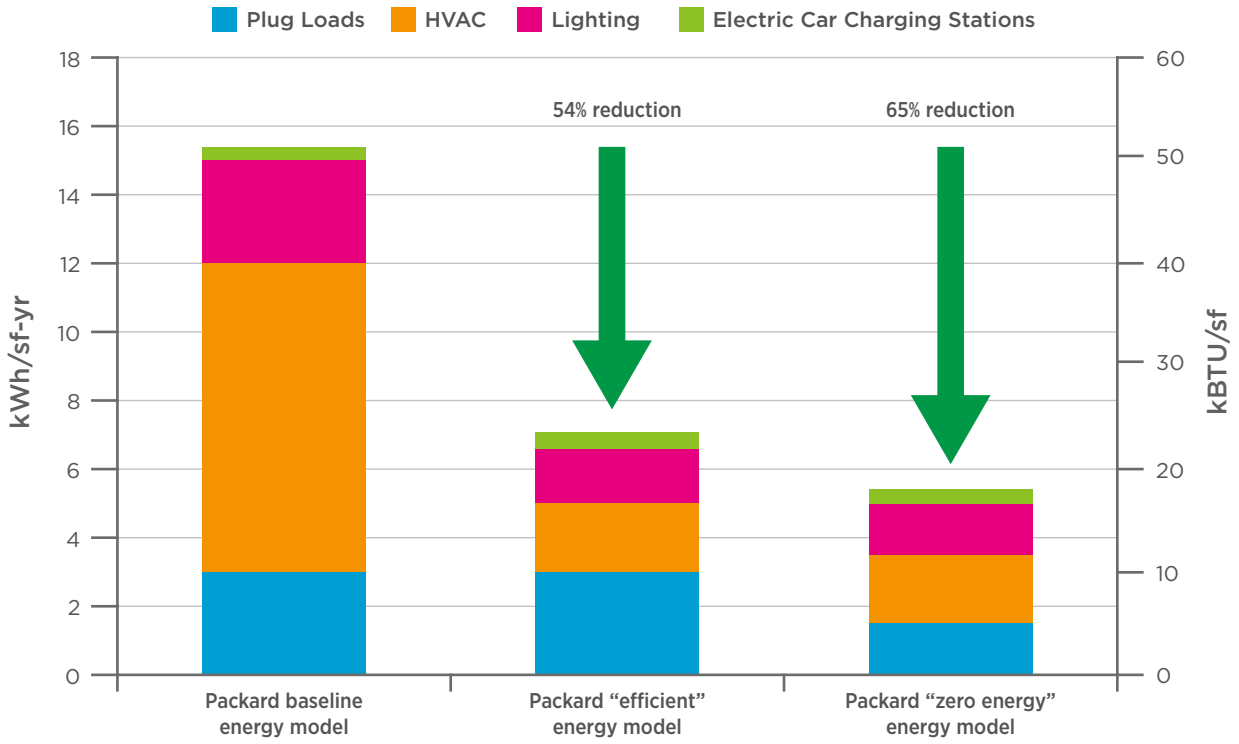
- Exterior shading elements such as window overhangs mounted louvers were credited with contributing to thermal energy savings in the model, sufficient to reduce the HVAC system size in 33 percent of the participant's responses.
- The design firm for a 10,000 sf building attributed part of their complete elimination of cooling systems to the use of shading devices.
- The use of electro-chromatic glass as a shading device was cited as a significant reduction in the HVAC system in nearby zones nearby.

34. NBI 2014 Getting to Zero Status Report Study.

**Interior Shading Devices**. Interior shades and blinds are moving beyond the reliance on a drawstring operated (or not) by occupant and becoming increasingly automated with a manual option. Reducing glare and heat by time of day and orientation is a strong strategy but it must compliment the daylighting strategy, the design intent for views, operational windows and natural ventilation aspects and the variables of occupant preference. Despite these complications, interior shades and blinds – both louvered and rollers - were included in over 50 percent of the projects with a combination of automation and manual controls. The benefits of thermal savings and occupant comfort were cited by the design teams as drivers for the selection of the automated systems.

After applying a good envelope design and passive strategies, lighting control, HVAC and plug loads were the pillars of getting to zero. An example of one of the survey building's whole building energy savings by system is shown in Figure 49.

Figure 49: Example of Energy Saving Strategies by System




Source: EHDD Architects

## OCCUPANT ROLE IN ENERGY PERFORMANCE

Occupants are playing a greater role in the energy impact of commercial buildings. Section 6 provides the operator and occupant perspective on this role. The majority of the design team participants (74%) said yes to "Does the design rely on the occupant for some part of the success of the controls operations?" and brought a variety of occupant engagement with controls into the plan. Approximately one quarter decided to keep the system controls autonomous.

The most common strategy employed was the use of a public energy dashboard by 96 percent of the design team participants as part of their energy reduction strategy, and the only project without one is currently considering it. This was seen as having a combined benefit of having a public demonstration of the firm's 'green' or energy efficiency commitment, as well as possibly influencing even a small fraction of the building's energy use through occupant behavior in response to the display. For these buildings, even a one to two percent energy reduction is key to making it to ZNE.

The design firm participants cited strong belief in the role of occupants in "Getting to ZNE", and yet also recognized that they can be an Achilles heel of the energy performance. Some of the quotes and comments include:

- "Absolutely, facilities personnel are critical, education of occupants is important too."
- "The building is currently core and shell, and therefore the success will be highly dependent on the tenants that move in and their consideration of the building's overall sustainability goals." "Lights show red/green to see when windows should open or close and occupants receive text messages. Occupants are responsible for opening windows, then the HVAC zones shut off."
- **"If they override the operable windows, then the HVAC unit turns on and savings are lost."**
- "The operable windows and motorized operable skylight are manually operated. Night plug loads are reduced by a manual kill switch. When the occupants all leave, the last one out shuts the building down."
- **"Internet Technology (IT) people won't let some equipment shut off at night because that's when they need to push updates. IT became an inhibitor to agency equipment use and its contribution to plug loads."**
- "Systems are set up to be completely automated, with the exception that we rely on the occupants to shut everything off when they leave."
- **"It was a perfectly good building until the people moved in!"** *Director of Facilities at a large school district in the Northwest (not a part of this study)*

It could be concluded that education of operators and occupants needs to be an early, not a last, step toward meeting energy performance targets.

## SUMMARY

- These buildings, unlike most buildings in North America, have specific energy targets and intentions for ongoing monitoring and performance feedback. This cycle of information helps with the assessment and refinements to identify areas that are not performing and to dial down energy use.
- 100 percent of respondents identified setting energy targets as very important or critical to the design process and outcomes.
- The projects primarily used a High Performance or a LEED building as the baseline, with only 30 percent identifying code as their baseline.
- The energy software, eQuest, was by far the most frequently utilized (45% of responses), likely because it is free software and is commonly used as an energy software for LEED submissions.
- Most firms utilized more than one energy modeling software and noted that for radiant heating/cooling systems and natural ventilation, Integrated Environmental Solutions (IES) and Thermal Analysis Simulation (TAS) software provided improved analysis.
- These buildings have a greater proportion of ground source and air source heat pumps, plus radiant heating and cooling distribution with these high efficiency HVAC systems controls, contributing to the low energy use of these buildings.
- The energy use (modeled and metered) of these buildings collectively is an average EUI of just 22 kBtu/sf/yr while the American national average is 93 kBtus/sf/yr.
- Data on the building's projected or metered energy use was well beyond baselines, as follows:
    - > Lighting Power Density (LPD) 40-60 percent less than code.
    - > Design energy targets for plug loads 60 percent less than standard baselines.
- System level contribution and comments on the whole building projected energy savings was cited as follows:
    - > Lighting > 15 percent of whole building projected energy savings and never less than 11 percent of the overall savings, with daylighting controls as the most common reference.
    - > HVAC controls >15 percent of the whole building savings. For HVAC, the strategies cited were to apply passive strategies first, with controls for natural ventilation, night flush and thermal set point controls.
    - > Plug load controls recognized at either >15 percent or six to 10 percent of whole building energy savings.
    - > Exterior shading through window overhangs and louvers contributed to thermal energy savings in the

model sufficient to reduce the HVAC system size in 33 percent of the responses.

> Interior shades or blinds - louvered and rollers - were included in over 50 percent of the projects with a combination of automation and manual controls driven by benefits of thermal savings and occupant comfort according to the design teams.

- Occupant's role in the energy savings was seen as key to getting to low energy outcomes, with findings as follows:
  > The majority of the design team participants (74%) brought a variety of occupant engagement with controls into the plan, while approximately one quarter decided to keep the system controls autonomous.
  > The most common strategy employed was the use of a public energy dashboard. This was used by 96 percent of the design team participants.

## SECTION 8

# TEN TAKEAWAYS

At the front end of the survey were a set of *Ten Takeaways* that captured the participants' ranking and commentary on high-level topics regarding controls. We found many areas that were strongly aligned and a few others where opinions were opposing. The dozens of design team participants surveyed had an impressive depth of experience with high performance and ZNE buildings,[35] and their lessons are of strong value to the industry even where there are conflicting responses.

The survey examined the responses by a) size and type of buildings, b) participant experience and c) system(s) type to look for correlations in the groupings of responses. For example: Did all smaller project designers tend to advocate for fewer or simpler controls, or were the referenced problems associated with a particular HVAC system? The survey did not observe alignments based on those three parameters in this small dataset. Rather, there are common lessons and advice that repeat across almost all participants and questions. Based on this, the Ten Takeaways findings are presented in this Section organized in two sub-sections:

1. Quantitative Questions – the questions with ranked responses and key quotes.
2. Commentary on Controls – A summary of the statements on open-form questions.

Throughout this section, direct quotes are shown in quotation marks. Paraphrased feedback from survey participants is shown in italics.

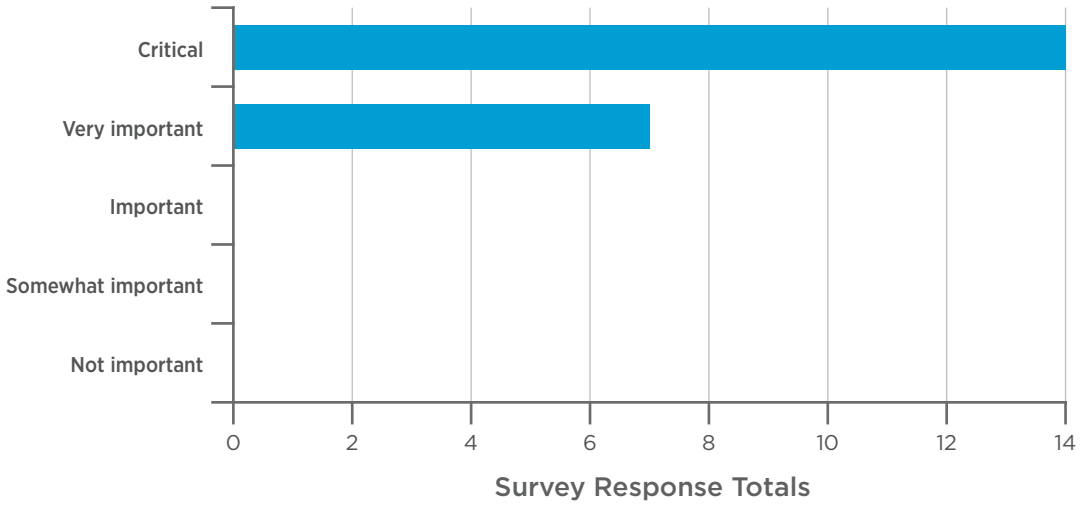
### RANKED QUESTIONS

#### Question 1. How important are building control strategies to ensure a ZNE outcome?

All the participants ranked controls as either very important or critical (33% and 67% respectively).

35. Over half of them have been in the profession > 10 years, and they have, on average, worked on 4-5 ZNE buildings (see Section 2).

Figure 50: The Importance of Control Strategies




**Controls are Critical – direct feedback from participants:**

> *Controls are very important to all buildings, ZNE or not.*
> *When doing commissioning (Cx), controls really help drill down to granular level.*
> *Plug load controls, lighting controls and whole-building controls are key to success.*
> *Controls are a sub-trade of a sub-trade - they should be a first-tier (separate) contractor.*

### Question 2. Would you select the same control systems for a similar building today?

Over three-quarters of the participants (77%) would select the same controls system for a similar building today.[36]

### Question 3. Considering that passive design strategies and improving technology efficiencies are reducing building energy use, please indicate if the value of the following control systems is increasing or decreasing.

On average, over three-quarters of the participants (78%) thought that the value of a wider range of controls systems is increasing, even while building energy use is being reduced from other factors such as passive design and improved technology efficiencies (Table 7).

Table 7: The Value of Controls Is Increasing

| | Major Decrease | Decreasing | No Change | Increasing | Major Increasing | No Opinion or N/A |
|---|---|---|---|---|---|---|
| Whole Building Controls | 0 | 0 | 3 | 10 | 9 | 1 |
| Lighting Systems | 0 | 0 | 1 | 12 | 9 | 1 |
| Daylighting Controls | 0 | 2 | 2 | 11 | 8 | 0 |
| Automated Shades & Glare Controls | 0 | 0 | 5 | 7 | 7 | 4 |
| HVAC Controls | 0 | 0 | 4 | 15 | 4 | 0 |

36. Most of the buildings surveyed were < 5 years since construction.

| | Major Decrease | Decreasing | No Change | Increasing | Major Increasing | No Opinion or N/A |
|---|---|---|---|---|---|---|
| Plug Loads | 0 | 0 | 1 | 10 | 9 | 3 |
| Server Closets and Data Mgmt | 0 | 0 | 5 | 9 | 5 | 4 |
| Totals | 0 | 2 | 21 | 74 | 51 | 13 |
| Percent per Response | 0% | 1% | 13% | 46% | 32% | 8% |
| Percent selecting Increasing or Major Increasing | | | | 78% | | |

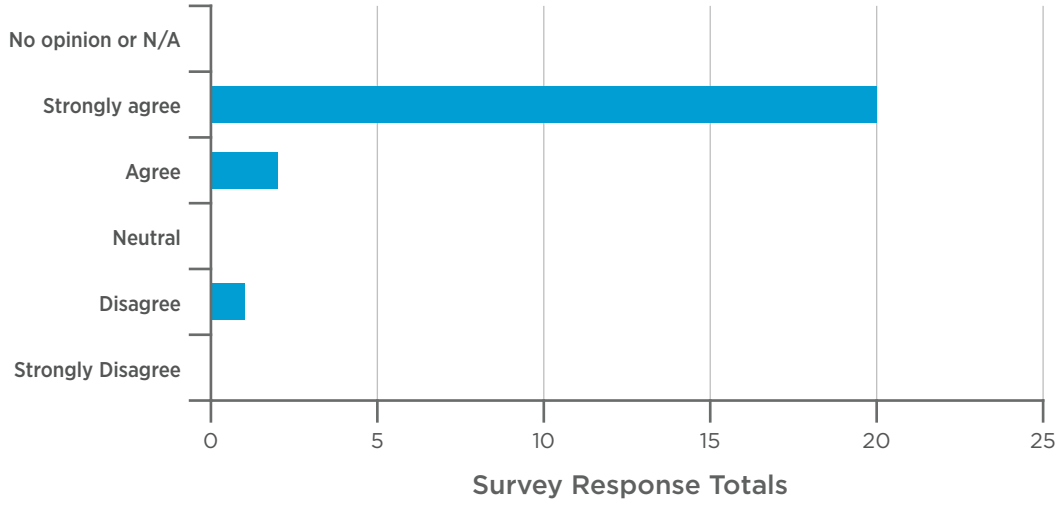
**Question 4. Please indicate your response to the following statements:**

a) Controls are getting easier to design and specify.
b) The ability to integrate controls from multiple systems is improving.
c) The Internet of Things (IoT) is helping simplify the path to ZNE.
d) Control communication platforms and protocols between systems need improvement.
e) Projects always have some control problems.

**Responses:**

- **a - c)** Most participants were in the middle ground on whether controls are getting easier to design and specify, if integrating controls was improving and if the *Internet of Things* (IoT) was simplifying the path to zero, with the majority being neutral.
- **d)** Almost all of the designers agreed or strongly agreed that control communication platforms and protocols between systems need improvement (82%).
- **e)** Most designers strongly agreed (87%) that "Projects always have some control problems" (Figure 51). *It is not strictly a matter of whether an open source or proprietary system is used. It's a matter of writing a detailed sequence of operations, having a great relationship with your vendor and requiring accountability for integration.*

Figure 51: Do Projects Always Have Some Controls Problems?



## COMMENTARY ON CONTROLS

The additional set of six takeaway questions covered overlapping topics and were open-field format responses regarding controls. The questions were:

Question 5. What would you carry forward to your next design?
Question 6. What advice would you offer to other designers to successfully incorporate control strategies in a ZNE building?
Question 7. What would you not do or do differently next time?
Question 8. How can designers best ensure that occupants contribute to (not detract from) zero net energy goals?
Question 9. What were the biggest surprises for you regarding the overall controls for this project?
Question 10. What is emerging in the intelligent building controls field that you consider noteworthy or is a game changer?

This Commentary Section provides detailed input from the design team participants, with their input and responses grouped by themes that emerged across multiple questions. Direct quotes are in quotation marks and paraphrased responses are in italics.

### Question 5. What would you carry forward to your next design? Question 6. What advice would you offer to other designers to successfully incorporate control strategies in a ZNE building?

Summary of Questions 5 and 6:

- **Integrate the controls sub-contractor - not just the controls**. The controls sub-contractor should be a first-tier contractor and involved from the start of the project. The building facilities and IT staff should be a part of early interaction with the controls sub-contractor as well, if possible. The contract and specifications for their work should be robust and include sufficient post-occupancy time for training the building operator, owner and/or occupants as well as full system trending, commissioning and ongoing fine tuning. The dashboard on energy use should be a part of their responsibility. Some projects have found success in using a Controls Integrator whose responsibility it is to ensure that the building's controls are meeting the design intent.
- **Meter and monitor then track and share actual performance**. Participants unilaterally agreed that, although the level varies by project, electrical panel-level load isolation, meters, sensor points, monitoring and the method of feedback must be at the forefront of designing for high performance. Integrate into the design a good holistic submetering system with built in analytics. Consider hardwired as well as wireless to avoid interference for the data collection. Without accurate and sufficient metering and properly operating controls, "all bets are off" for performance results. The early involvement of the operator is a key to getting things right.
- **Design the building right first**. No other factor influences energy use as much as the initial design and, in turn, influences the need for mechanical systems and controls. Many participants referenced the overall design as a primary strategy to get to net zero. The ability to apply effective controls can be aided or inhibited by design factors associated with the size and locations of windows, exterior shading, building orientation and massing. Most buildings utilized passive cooling strategies, daylighting, operable and automated windows and heat recovery. The building configuration, envelope characteristics and material selections all are pre-control areas that later impact the operational aspects of systems and controls. These participants utilized their design expertise to start with a shell that incorporated best practices for minimizing energy needs with consideration of the layering of systems and controls that would be affected. Their arguments to include the controls sub-contractor as a key and early member of the design process would further support the outcome-based performance goals of advanced buildings.

- **Design for off**. Design systems for the default position to be powered off or down. Determine the hours and methods when you can turn the systems off. Simplify the action needed for occupants to select off and make it the default. Passive systems should displace the active systems, putting them in off-mode as much as possible.
- **Select leading technologies and incorporate system controls for high performance**. The participants said they would continue to use leading edge systems combined with the controls to manage, monitor and ensure performance and drive toward zero net energy outcomes. The systems cited for use in future projects included ground-source and air-source heat pumps, radiant heating and cooling, dedicated outdoor air systems, heat recovery (even in temperate climates if heating by air), thermal storage with night operating chillers, variable refrigerant flow systems, automated blinds, automated windows, demand controlled ventilation via $CO_2$ sensors, integrated daylighting lighting systems, smart occupancy sensors for plug loads, and renewable energy production systems.
- **Simple is smart**. From the set of participants representing 23 projects, there was a sub-set of five or six that included the theme of "simple" throughout their responses. Their projects and experience covered the full range of sizes, types and system selections, so their strong message did not seem to be biased by a poor experience with a particular control system or product. Rather it was represented as a design and operational philosophy – "Keep it simple." Although the value of more affordable and extensive sensors, wireless networks, increased data and granular feedback held a larger constituency in this small survey – and remains the trend in building design and monitoring - the commentary on 'simple' warrants sharing. The small but vocal group on this topic, here and at other efficiency and design events, are using design and controls to *minimize* not only energy use, but the overall complexity of building management for next generation buildings. Some of the commentary on simplicity included:
    > **Keep it simple**. 'Passive and simple' has a lot to do with attaining ZNE. Better passive buildings need fewer controls and are more robust. Complicated and sophisticated buildings can be more than the owner/operator can handle. Overreliance on controls can cause problems. Complex systems may be less sustainable due to lots of components.
    **"Keep complexity of controls and points of failure to a minimum."**
    *System operation should be as clear and simple as practicable. Simply sequence instead of chasing a complicated and optimized sequence. Would go to a simpler controls and HVAC system in general because getting someone out to troubleshoot and tune is difficult. We monitored much more than they actually used – could monitor just the basics of HVAC, lights, plugs, misc. with 30 minute data – just need enough to see trends. We created an over-complex design for the people running the building and the location. Consider the skills of the facility staff. Select plug load controls strategy wisely: simplicity is important. If there are many different people, you need a simple solution. Programmable power strips, etc., are too complex for most people to actually use. Understand occupants: a good occupant is better than the best control system.*
    > **Alternate point – Make it work**:
    **"Everyone says "keep it simple" but I don't necessarily agree. "Make it work" might be more on the mark."**
    *Focus on this in design and particularly specifications, then follow up closely with the right members of the design team and the certified commissioning authority (CxA) during construction and post-occupancy. Granularity is not overrated EVER; dashboards are often too broad to be useful.*
- **Optimize settings and strategies**. The design firm participants shared some feedback on system level settings and strategies for low and zero energy buildings.
*Separate conditioning from ventilation, which allows you to do much better at reducing runtime. Radiant systems should use slab temperature sensors to measure the thermal mass of the concrete. This is the best thing we did because ASHRAE has very conservative numbers to model this concrete assembly. Operate the building around the outside, rather than the inside, temperature - in Seattle 1/2 of the hours per year are sufficiently temperate*

*to naturally ventilate and keep mechanical systems off. Thermostatic controls should be based on building mass temperature and mean radiant temperature of space."*

- **Some sage words**
  - > "Never settle for off-the-shelf answers to off-the-shelf questions, especially early on."
  - > **"The accounting folks thought we couldn't do this on budget so proposed early value engineering. Hold your ground - we met the budget and kept all components."**
  - > "Have 'if you don't show up for meetings you're fired' in the contract language – time is money."
  - > "Be flexible and think out of the box – you can't be too dogmatic about what you want it to do."

### Question 7. What would you do differently?

Here are some specific changes designers noted they would make if they could redesign their building.

- **Increase control contractor role and commissioning (Cx)**. *Incorporate better, more robust specifications for the controls sub-contractor, Cx and the Cx agent, requiring greater time and involvement post-occupancy. Increase the role of education from the controls sub-contractor to the owner and operator. Have the controls sub-contractor involved early, and provide the dashboard.*
- **Ensure sufficient metering**. *Separate panels for system monitoring, especially plug loads, and ensure built-in circuit monitoring. Increase the number of meters integrated into the controls strategy upfront.*
- **Consider system changes**. *Utilize newer technology systems such as Variable Refrigerant Flow (VRF) and Radiant Systems. Control the Radiant by slab, rather than by space temperature. Integrate occupancy sensors with HVAC and lighting. Advocate for shades/blinds. Leave ceiling fans outside of the BMS and ensure fan controller is from the manufacturer to reduce noise. Control the VRF by its own proprietary system rather than a third-party Building Management System. To keep potential points of failure to a minimum we chose a zonal/VRF system rather than built up air handing units (AHUs) with variable air volume (VAV).*
- **Problem areas**:
  - > "The principal issue with every ZNE building that I have studied carefully (designed by others) has been control systems, measurement and verification. This includes the building that I was responsible for."
  - > *When the controls fail (typically sequences, not components) they fail catastrophically. This means that because the building is tightly tuned, a small problem can cascade and grow.*
  - > *Economizer controls on Rooftop Units (RTUs) are a bugbear. Even the smallest buildings take significant Commissioning (Cx).*
  - > *While most Cx Agents know HVAC controls, they do not know daylighting controls very well.*
  - > *Occupancy sensors are a love/hate relationship – a simple technology that ends up with lots of problems – sometimes a good occupant can do just as well with a switch.*

### Question 8. Occupants – how do you ensure they contribute to (not detract from) low-energy goals?

- **Education and training**. This is first in this list because it was referenced repeatedly across participants and as a response to many questions. Have clients/owners promote and facilitate occupant workshops on how the building operates, their interaction for personal comfort, control and energy performance. Have a "Welcome Guide" on the building at occupancy or tenant turnover.
- **Early involvement**. Include occupants in the design intention from the start of the project, and have a forum for ongoing discussion and vesting in the outcomes of performance.
- **Feedback**. Include real-time and ongoing feedback to occupants on their impact and the building's performance via dashboards, emails, cues for system changes (operable windows) and signage. Information is powerful. Consider gamifying energy. *To control plug loads, you can even assign particular outlets to specific people – then their energy use is explicit. Alternate point: It cannot be completely left up to signage - people don't read. "It's all about a Post Occupancy Evaluation (POE) to understand behaviors."*

- **Engagement**. You need to motivate the occupants to make the building work – identify ways to engage occupants based on their values and interests. Provide individual controls over their environments, but ensure a master setting that returns systems to the default setting, as they may do things you never imagined. Use programming to help the system meet targets while providing user flexibility.

**"The Toughest Thing to Control is Occupants –** *They Make (or Break) Energy Performance***"**

### Question 9. What were the biggest project surprises?

- Collecting energy data is rare.
- Systems were not interoperable.
  - > *Lighting system didn't at first talk to other systems.*
  - > *Takes more work than it should to make different systems report into one central system.*
- Contractor resistance and skills were an issue.
  - > *The contractor was negative regarding their role and the likelihood of our integration being functional - said 'we don't do that, this won't work, and you'll have problems. . .'*
  - > *Contractors often lacked familiarity with this sort of hybrid/passive HVAC.*
  - > *Contractor concern about thermal comfort callback issues inhibited their input on the best strategy for energy performance.*
  - > "I was surprised by how much the controls specialist did not understand about the HVAC and lighting design intent."
- ZNE goes well beyond the traditional Commissioning (Cx) process.
  - > *Everything looked OK at first, but upon digging into sub-metering data it turned out that there were differences between design specs and plans and actual energy use/schedules. It took a concerted effort to do full analysis of the how and why of systems operation. We need to plan to loop manufacturers back in during Cx and for one year post-occupancy. There is a new role for a 'Controls Integrator.'*
- The amount of energy wasted by occupants leaving lights on all the time was surprising.
  - > "The worst assumption was that I could teach people to turn lights off."
    - » *Good daylighting sensors meant they didn't notice lights were on. Should have put sensors in at the start.*
  - > *Hassle factor of people turning lights on means that they use less controlled lighting - and often don't even use task lighting.*
  - > *10-15 fc seems to be about where people get up and turn on the lights.*
- Conflicts with complex sequences emerged.
  - > *Overcomplicated decision methods combined with real thermal issues created a very tense troubleshooting scenario.*
- Conflicts between system architecture and controls architecture caused problems.
  - > *It was a real challenge to control a VRF system with an external BMS: necessary points don't carry through.*
- Lack of accuracy in electrical sub-meters and difficulty in setting them up was a challenge.
- There is often a lack of correlation between actual and predicted performance.
  - > *Lighting system was turned off more often by daylighting system than predicted.*
  - > *Control system intervention more often than model predicted.*
  - > *Needed to factor in the use of propane for backup heating and kitchen.*
- Staging of the various outcomes, including the solar component, is challenging.
- The lack of granularity is a real problem.
  - > "We worked so hard on modeling and didn't spend enough time on the controls."

### Question 10. What are emerging notable or game-changing trends for intelligent building controls?

- **Integrated control systems.**
  - A. **Integration of end-uses and networks with automated control system management.**
    - Lighting and HVAC controls share temperature, occupancy and schedule data that is used for energy management and space utilization.
    - This is the inevitable solution but needs to be developed for relatively small building projects and must be affordable for such projects.
  - B. **Adaptive and occupant-based controls.**
    - Key missing piece is applying adaptive controls and artificial intelligence to buildings. Controls should be proactive rather than reactive. Some examples cited are:
      - > Nest thermostat.
      - > Comfy thermal comfort app.
    - Luminaire level lighting controls – these allow for customized light levels, control and data gathering per fixture.
    - Weather adaptive forecast integrated controls. Examples cited:
      - > Rainwater harvesting system with a smart controller that ties to weather forecast – if it sees rain in the forecast, it will wait to water plantings.
      - > Building-level thermal energy storage could be tied to weather forecasting to inform precooling; weather forecasts that lead to actions in the BMS would be very advanced.
- **Monitoring and feedback.**
  - A. **Building dashboards and simple monitoring systems.**
    - Dashboards that double as a simplified Building Management System.
    - Simple data monitoring systems and ways to easily access information.
    - Low cost dashboards and visualization.
    - Smart phone apps – should be free with a clean interface.
    - Ways that help people understand, on a personal level, their impacts on the building performance can help and provide control. Examples cited:
      - > QA Graphics.
      - > Lucid Solutions.
      - > Daikin ITouch Controller.
      - > Reliable Controls.
  - B. **Fault detection with early warning for energy use or equipment failures.**
  - C. **Energy model-based control** – intertie of the energy model to post occupancy controls to predict and inform how building will operate.
- **Utility Demand Response Programs** – "This is definitely a game changer."
- **Other:**
  - Robotics.
  - DC building systems.
  - Energy storage.
  - Protocol standardization.

## SUMMARY

The Ten Takeaways represent a summary of the overall perspective from the participants. Although there are variations worth reviewing within each of the questions that may be relevant to individual projects, the aligned responses are listed below.

**1. How important are building control strategies to ensure a net zero energy outcome?**

- All the participants ranked controls as either very important or critical (33% and 67% respectively).

**2. Would you select the same control systems for a similar building today?**

- Over three-quarters of the participants (77%) would select the same controls system for a similar building today.[37]

**3. Considering that passive design strategies and improving technology efficiencies are reducing building energy use, is the value of (a range of) control systems increasing or decreasing?**

- Over three-quarters of the participants (78%) thought that the value of a wider range of controls systems is increasing or majorly increasing, even while building energy use is being reduced from other factors such as passive design and improved technology efficiencies.

**4. Please indicate your response to the following statements: a) Controls are getting easier to design and specify. b) The ability to integrate controls from multiple systems is improving. c) The Internet of Things (IoT) is helping simplify the path to net zero. d) Control communication platforms and protocols between systems need improvement. e) Projects always have some control problems.**

- a - c) Most participants were in the middle ground on whether controls are getting easier to design and specify, if integrating controls was improving and if IoT was simplifying the path to zero, with the majority being neutral.
- d) Almost all of the designers agreed or strongly agreed that control communication platforms and protocols between systems need improvement (82%).
- e) Most designers strongly agreed (87%) that "Controls always have some problems." It is not strictly a matter of whether an open source or proprietary system is used. It's a matter of writing a detailed sequence of operations, having a great relationship with your vendor and requiring accountability for integration.

**5. What would you do again?** and **6. What advice would you offer to designers?**

- Integrate the controls sub-contractor - not just the controls.
- Meter and monitor then track and share actual performance.
- Design the building right first.
- Select leading technologies and incorporate system controls for high performance.
- Simple is smart. Keep it simple. Alternate point – Make it work.
- Optimize settings and strategies.

**7. What would you do differently?**

- Increase control contractor role and commissioning.
- Ensure sufficient metering.
- Consider system changes.
- Avoid problem areas.

**8. Occupants – how do you ensure they contribute to (not detract from) low-energy goals?**

- Education and training.
- Early involvement.

37. Most of the buildings surveyed were < 5 years since construction.

- Feedback.
- Engagement.

**9. What were the biggest project surprises?**

- Collecting energy data is rare.
- Systems were not interoperable.
- Contractor resistance and skills were an issue.
- ZNE goes well beyond the traditional Commissioning (Cx) process.
- The amount of energy wasted by occupants leaving lights on all the time was surprising.
- Conflicts with complex sequences emerged.
- Conflicts between system architecture and controls architecture caused problems.
- Lack of accuracy in electrical sub-meters and difficulty in setting them up was a challenge.
- There is often a lack of correlation between actual and predicted performance.
- Staging of the various outcomes, including the solar component, is challenging.
- The lack of granularity is a real problem.

**10. What are emerging notable or game-changing trends for intelligent building controls?**

- Integrated and lower cost control systems.
  - > The integration capabilities of end-uses and networks with automated control system management are improving.
  - > The cost of interconnectivity is decreasing.
    ***"Whether through Wi-Fi, ZigBee, or EnOcean type technology, the ability of sensors to report on conditions will provide more data for the Intelligent Systems to be able to do a better job in their assigned areas."***
  - > Adaptive and occupant-based controls and weather adaptive control settings are emerging.
- Monitoring and feedback.
  - > Building dashboards and simple monitoring systems will be significant.
  - > Fault detection with early warning for energy use or equipment failures can have a large impact.
- Energy model-based control.
- Utility demand response programs.
- Other:
  - > Robotics
  - > DC building systems
  - > Energy storage
  - > Protocol standardization

The Ten Takeaways section of the survey not only sought to document the very important role that controls play in net zero energy buildings and the increasing value that they provide, but also allowed the survey respondents to provide feedback based on their experiences. Characterizing this feedback into particular themes and takeaways was challenging due to the wide range of responses and occasionally conflicting answers. A deeper analysis of the feedback received, and a synthesis of the recommendations reached, follows in the conclusions section of this report.

# SECTION 9
# 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. 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 set of buildings in this study are 23 leading edge designs incorporating a range of strategies and technologies that share a common intent to minimize energy use and get to zero net energy performance. Their design teams also share many common perspectives on the value of, and role of, controls in these buildings. Every project design firm selected 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 sub-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 sub-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, according to design firm responses, 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 the failure of components 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, as shown in this study, have more high performance systems, integrated energy production, and tend toward greater system integration, metering, monitoring and feedback as their standard practice. Due to this, research participants 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 of 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 percent less than most new buildings today and over 75 percent less than average existing buildings, with renewables making up the small balance of energy needs. "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.[38] 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 most frequently provided through manual and automated windows (natural ventilation) and/or dedicated outside air systems. Lighting is always integrated with both daylight design strategies and controls, resulting in lighting power densities that are 40 to 60 percent less than a code building. The pursuit of reducing occupant-driven plug load energy remains a challenge, but well over half of the projects incorporated some control technologies such as smart power strips, outlet level controls or centralized power management, and 100 percent of them incorporated energy-use dashboards and occupant feedback. The majority of design firms attributed HVAC, lighting and plugs each with having a greater than 15 percent impact on the energy savings, so the success of the control of these systems means the success of the energy goals.

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 randomly applied (or not) by the occupant. Over half of the projects included interior shades or blinds with a combination of manual and automated controls driven by thermal energy and occupant comfort benefits according to the design firms.

## OCCUPANTS ARE A NEW OPERATOR

The role of occupants on energy outcomes has never been greater. Although designers and operators see the value and importance of all system and building level controls increasing, despite reductions in baseline energy use, the occupant impact remains a wildcard. Fully 74 percent of the buildings rely on the occupant for some part of the controls success, 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 and manual and controls, where systems return to a default triggered by time or sensor and messaging.[39] Yet nearly 70 percent of the occupant respondents said they do not receive any communication on the topic of their role in reducing energy consumption in their building, further indicating a gap from design intent to operations and occupancy.

These buildings had generally very high levels of occupant satisfaction, regardless of control access. Satisfaction levels with the lighting and the daylighting were: 70% and 75% respectively; indoor air quality and heating: 63% and 57% respectively; and plug load controls (45%); while cooling had a high unsatisfied response (40%). A majority of the respondents did want some degree of greater control modified by comments that a bit more would go a long way.

Although the issues with cooling thermal comfort were isolated to a small set of the buildings, the occupant response was strong and vocal regarding their dissatisfaction. 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. The occupants, according to one design firm, are the best building 'sensors' and building owner/operators need their perspective to tune 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.

38. 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.
39. "Design for Off" was developed and trademarked by Ecotope and referenced by several projects.

## GAME CHANGERS INCLUDE INTEGRATION, ENGAGEMENT AND A NEW UTILITY WORLD

The survey included a blank section, or open ended question in interviews, in response to a 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. 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; relate energy use to higher values and goals based on dashboards; the use of computer programs, smart phone apps, wearable technology (e.g., smart watches) or other visual messaging, were also forms of engagement and trends.

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 distributed generation (located at multiple sites and owned by a wide variety of entities) due to increased renewables on buildings and the daily/seasonal variations in energy production and use are creating new load curves for utilities and 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 change the formula for what makes sense when and where.

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 is the industry that manufacturers these systems, designs, builds, operates, owns or occupies buildings. 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 coupled with environmental stewardship. The implications of this study lie in the interests of the reader, yet there are clear messages that apply across most industries.

The complexity of controls in both quantity and derived data 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 and from building to energy system.

**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 buildings and increased drivers for energy efficiency. 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 Sub-Contractor**. The controls sub-contractor needs to be a primary team 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 sub-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.

Working on these recommendations through the chain of building and controls manufacturing, design, 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, efficiently and in an environmentally sound manner. Based upon the advances in design and operations of this elite class of ultra-high performance ZNE buildings, coupled with attention the buildings sector is getting from entrepreneur and tech startups in the Silicon Valley, this report anticipates the pace of change in the controls industry to accelerate even more rapidly in the coming decade. This study provides a stepping stone for more effective controls in the next generation of ZNE buildings.

## APPENDIX A

# LIST OF TARGET BUILDINGS

The buildings targeted for this project included more than 80 ZNE buildings across North America and have been listed in NBI's public Getting to Zero Database.[40] All were considered as potential candidates for design team and operator surveys. A total of 23 design team interviews were completed and a total of six operator interviews were completed. Table 8, below, highlights the buildings for which the design team was interviewed. Other buildings were targeted (Table 9), but the research team was not successful in connecting with the design team to include the projects in this study.

**Table 8: Buildings included in this study for which design teams were interviewed**

| Project | Location | Size Range | Building Type | Retrofit | Operator Survery Completed |
|---|---|---|---|---|---|
| 435 Indio Way | CA | 25k - 50k sf | Office | X | |
| Bullitt Foundation Cascadia Center for Sustainable Design and Construction | WA | 50k - 100k sf | Office | | X |
| Cornell NYC Tech First Academic Building | NY | over 100k sf | Education | | |
| David and Lucile Packard Foundation | CA | 25k - 50k sf | Office | | X |
| DPR Construction San Francisco Office | CA | 10k - 25k sf | Office | X | |
| Exploratorium | CA | over 100k sf | Other | X | |
| Hanover Page Mill Building | CA | 50k - 100k sf | Office | | |
| IDeAs Z2 Office Building | CA | 5k - 10k sf | Office | X | |
| Lane Community College, Downtown Academic Center | OR | 50k - 100k sf | Education | | |
| Leslie Shao-Ming Field Station at Jasper Ridge" | CA | 5k - 10k sf | Education | | |
| Massachusetts Division of Fisheries & Wildlife Field HQ | MA | 25k - 50k sf | Office | | |
| Morphosis Architecture Studio | CA | 10k - 25k sf | Office | | |
| NREL Research Support Facility | CO | over 100k sf | Office | | X |

40. Available at http://newbuildings.org/getting-to-zero-buildings-database.

| Project | Location | Size Range | Building Type | Retrofit | Operator Survery Completed |
|---|---|---|---|---|---|
| Rice Fergus Miller Office & Studio | WA | 25k - 50k sf | Office | X | |
| Rocky Mountain Institute Innovation Center | CO | 10k - 25k sf | Office | | |
| Sacred Heart Schools Stevens Family Library | CA | 5k - 10k sf | Education | | X |
| San Luis National Wildlife Refuge HQ and Visitor Center | CA | 10k - 25k sf | Office | | |
| UC San Diego J Craig Venter Institute | CA | 25k - 50k sf | Other | | |
| UniverCity Childcare Centre | BC | 5k - 10k sf | Education | | |
| VanDusen Botanical Garden's Visitor Centre | BC | 10k - 25k sf | Assembly | | X |
| Watsonville Water Resources Center | CA | 10k - 25k sf | Office | | |
| Wayne Aspinall Courthouse & Fed Bldg | CO | 25k - 50k sf | Courthouse | X | |
| West Berkeley Public Library | CA | 5k - 10k sf | Library | | X |

Source: New Buildings Institute

Table 9: Other targeted buildings which are not included in this study

| Building Name | Location | Size | Building Type |
|---|---|---|---|
| Aldo Leopold Legacy Center | WI | 10k - 25k sf | Office |
| BEST Center at Laney College | CA | District | Education- higher |
| Cambridge MA - MLK School | MA | over 100k sf | Education- K-12 |
| Centennial PK-12 School | CO | 50k - 100k sf | Education- K-12 |
| Centre for Interactive Research on Sustainability (CIRS) | BC | 50k - 100k sf | Education- general |
| Centre of Excellence at Okanagan College | BC | 50k - 100k sf | Education- higher |
| Chatham University Eden Hall Campus | PA | District | Education- higher |
| Colonel Smith Middle School | AZ | 50k - 100k sf | Education- K-12 |
| Conrad N. Hilton Foundation | CA | 10k - 25k sf | Office |
| DPR Construction Phoenix Net Zero Office | AZ | 10k - 25k sf | Office |
| DPR Construction San Diego Net Zero Office | CA | 10k - 25k sf | Office |

| Building Name | Location | Size | Building Type |
|---|---|---|---|
| East Bay MET School | RI | 10k - 25k sf | Education- K-12 |
| Electrical and Computer Engineering Building and University of Illinois | IL | over 100k sf | Education- higher |
| Evie Garrett Dennis E12 Campus (Denver Schools) | CO | over 100k sf | Education- K-12 |
| First Housing Development Corp | FL | 10k - 25k sf | Office |
| Glenn York Elementary School | TX | 50k - 100k sf | Education- K-12 |
| Hillandale Elementary School | NC | 50k - 100k sf | Education- K-12 |
| IBEW Local 595 Zero Net Energy Center | CA | 25k - 50k sf | Education- general |
| Kaiser Permanente Antelope Valley Specialty Medical Office Building | CA | over 100k sf | Office |
| "Keene State College Technology, Design and Safety Building" | NH | 50k - 100k sf | Education- higher |
| King County Housing Authority Administration Building | WA | 25k - 50k sf | Office |
| La Escuelita Education Center | CA | over 100k sf | Education- K-12 |
| Lady Bird Johnson Middle School | TX | over 100k sf | Education- K-12 |
| Leon County Cooperative Extension | FL | 10k - 25k sf | Office |
| Locust Trace AgriScience Campus (High School) | KY | 50k - 100k sf | Education- K-12 |
| Los Angeles Harbor College Sciences Complex | CA | 50k - 100k sf | Education- higher |
| LPL Financial Center at La Jolla Commons | CA | over 100k sf | Office |
| MacArthur Elementary School | NY | over 100k sf | Education - K-12 |
| Market 1 | IA | 25k - 50k sf | Office |
| Melink Corporation Headquarters | OH | 25k - 50k sf | Office |
| Mills River Elementary School | NC | 50k - 100k sf | Education- K-12 |
| Mosaic Centre | AB | 10k - 25k sf | Office |
| Net Zero Plus Electrical Training Institute | CA | over 100k sf | Education- general |
| New Century Elementary School | NC | over 100k sf | Education- K-12 |
| North Shore Community College Health and Student Services Building | MA | 50k - 100k sf | Education- higher |
| Oberlin College Lewis Center | OH | 10k - 25k sf | Education- higher |
| Palmetto Bay Municipal Center | FL | 10k - 25k sf | Office |
| Pflugerville Elementary School | TX | 50k - 100k sf | Education- K-12 |

| Building Name | Location | Size | Building Type |
|---|---|---|---|
| Phipps Center for Sustainable Landscapes | PA | 10k - 25k sf | Public Assembly |
| Portland Community College Newberg Center | OR | 10k - 25k sf | Education- higher |
| Putney Field House | VT | 10k - 25k sf | Education- K-12 |
| Redding School for the Arts | CA | 50k - 100k sf | Education- K-12 |
| Richard J. Lee Elementary School | TX | 50k - 100k sf | Education- K-12 |
| Richardsville Elementary School | KY | 50k - 100k sf | Education- K-12 |
| Sandy Grove Middle School | NC | 50k - 100k sf | Education- K-12 |
| SMUD Net Zero Campus - East Campus-Operations Center | CA | over 100k sf | Office |
| Solana Ranch Elementary School | CA | 50k - 100k sf | Education- K-12 |
| State University at Albany ETEC Building | NY | over 100k sf | Education- higher |
| Staten Island Public School 62 | NY | 50k - 100k sf | Education- K-12 |
| Staten Island Public School 62 | NY | 50k - 100k sf | Education - K-12 |
| Student Services Center at Mesa College | CA | 50k - 100k sf | Education- higher |
| Student Success and Retention Center at East Los Angeles College | CA | over 100k sf | Education- higher |
| Turkey Foot Middle school | KY | over 100k sf | Education- K-12 |
| UC Santa Barbara Student Services Buildings | CA | District | Education- higher |
| United Therapeutics | MD | over 100k sf | Office |
| University of Minnesota Itasca Biological Station and Laboratories | MN | 10k - 25k sf | Education- higher |
| University of South Carolina Darla Moore School of Business | SC | over 100k sf | Education- higher |
| University of Wisconsin Arlington Agricultural Research Station | WI | District | Education- higher |
| Vernonia School K-12 | OR | over 100k sf | Education- K-12 |
| VF Outdoor HQ | CA | over 100k sf | Office |
| Zero Energy Nanotechnology Building at SUNY Poly | NY | over 100k sf | Education- higher |

## APPENDIX B

# GLOSSARY AND ACRONYMS

1. **Architecture 2030**: A non-profit organization established in response to the climate change crisis with the mission to rapidly transform the built environment from the major contributor of greenhouse gas (GHG) emissions to a central part of the solution to the climate crisis.
2. **AHU**: Air Handling Unit - A device used to regulate and circulate air as part of a heating, ventilating, and air-conditioning (HVAC) system.
3. **AC**: Alternating Current - An electric current where the flow of electric charge periodically reverses direction. The standard current for most systems in commercial buildings and homes.
4. **BAS**: Building Automation System - The automatic centralized control of a building's heating, ventilating, and air-conditioning, lighting and other systems.
5. **BMS**: Building Management System - A computer-based control system installed in buildings that controls and monitors the building's mechanical and electrical equipment such as ventilation, lighting, power systems, fire systems and security systems.
6. **CABA**: Continental Automated Buildings Association.
7. **Cx**: Commissioning - A method of risk reduction for new construction and major renovation projects to ensure that building systems meet their design intent, operate and interact optimally and provide the owner's expectations. This systematic process typically includes building HVAC, controls, lighting, hot water, security, fire, life and safety systems.
8. **CxA**: Certified Commissioning Authority - She/he performs as the leader of the commissioning team and is responsible for planning, organizing and facilitating the completion of the commissioning process on behalf of the owner.
9. **DOAS**: Dedicated Outdoor Air System - A type of heating, ventilation and air-conditioning system, which consists of two parallel system as dedicated outdoor air ventilation system and a parallel system to handle latent and sensible loads respectively to provide dedicated ventilation rather than basic conditioned ventilation.
10. **DC**: Direct Current - An electric current where the flow of electric charge is only in one direction.
11. **DDC**: Direct Digital Controls - An automated control of a condition or process by a digital device with more modern, granular and responsive update in comparison to older HVAC control systems.
12. **DOE**: Department of Energy.
13. **EIA**: Energy Information Administration.
14. **EIS**: Energy Information Systems - It is broadly defined as performance monitoring software, data acquisition hardware and communication systems used to store, analyze and display building energy data.
15. **EUI**: Energy Use Intensity - Expression of a building energy use as a function of its size or other characteristics (energy per square foot per year) i.e., kBtu/sf/yr.
16. **EOR**: Engineer of Record - A licensed professional engineer who develops the overall structural design and the structural design criteria for the structure and is responsible for the preparation of the structural engineering documents.
17. **EMS**: Environmental (or Energy) Monitoring Systems.

18. **HVAC**: Heating, Ventilation and Air Conditioning.
19. **IT**: Information Technology or Internet Technology.
20. **IES**: Integrated Environmental Solutions - An approach to environmental management which requires recognition of the linkages between different parts of the environment and adopts a range of tools to identify and manage environmental effects across the different parts to ensure co-ordination across institutional barriers, such as agency barriers.
21. **IoT**: Internet of Things - A process in which objects, animals or people are provided with unique identifiers and the ability to transfer data over a network without requiring human-to-human or human-to-computer interaction.
22. **LEED**: Leadership in Energy and Environmental Design – A set of rating systems developed by the USGBC for the design, construction, operation, and maintenance of green buildings, homes and neighborhoods to help owners and operators be environmentally responsible and use resources efficiently.
23. **LPD**: Lighting Power Density – It represents the load of any lighting equipment in any defined area, or the watts per square foot of the lighting equipment.
24. **NBI**: New Buildings Institute.
25. **OEM**: Original Equipment Manufacturer – it refers to the process where one company makes a part or subsystem that is used in another company's end product.
26. **O&M**: Operations and Maintenance.
27. **POE**: Post Occupancy Evaluation - The process of evaluating buildings in a systematic and rigorous manner after they have been built and occupied for some time.
28. **SAAS**: Software as Service – A software licensing and delivery model in which software is licensed on a subscription basis and is centrally hosted.
29. **TAS**: Thermal Analysis Simulation.
30. **USGBC**: U.S. Green Building Council - A diverse group of builders and environmentalists, corporations and non-profits, teachers and students, lawmakers and citizens that share the same vision of a sustainable built environment for all within the next generation.
31. **VRF**: Variable Refrigerant Flow - An HVAC technology where it uses refrigerant as the cooling and heating medium. This refrigerant is conditioned by a single outdoor condensing unit, and is circulated within the building to multiple fan-coil units.
32. **VAV**: Variable Air Volume - Type of heating, ventilating, and/or air-conditioning system where it varies the airflow at a constant temperature.
33. **ZNE Buildings**: Zero Net Energy Buildings - ZNE buildings have greatly reduced energy loads such that, over a year, 100 percent of the building's annual energy use can be met with onsite renewable energy. *Note: also called Net Zero or Zero Energy Buildings.*

## APPENDIX C

# SUPPORTING REFERENCES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