Charles Eley, FAIA, P.E., BEMP, Member ASHRAE, consulting architect/engineer, San Francisco

Smita Gupta, principal energy consultant, Itron, Sacramento, Calif.

Paul Torcellini, Ph.D., P.E., principal engineer for commercial buildings research, National Renewable Energy Laboratory, Golden, Colo.

Jon McHugh, P.E., Member ASHRAE, principal, McHugh Energy Consultants, Sacramento, Calif.

A Conversation on Zero Net Energy Buildings

Editor's Note: Recently, zero net energy (ZNE) buildings have moved from state-of-the-art small project demonstrations to a more widely adopted approach across the country among various building types and sizes. States such as California set policy goals of all new residential construction to be NZE by 2020 and all commercial buildings to be NZE by 2030. However, the market for designing, constructing, and operating ZNE buildings is still relatively small. We bring together distinguished experts to share their thoughts on making ZNE buildings more widespread and mainstream from a broad perspective, including governments, utilities, energy-efficiency research institutes, and building owners. This conversation also presents the benefits of ZNE and ways to achieve that goal in the design and operation of buildings. The following is a roundtable conducted by ASHRAE Journal *and Bing Liu with Charles Eley, Smita Gupta, Cathy Higgins, Jessica Iplikci, Jon McHugh, Michael Rosenberg, and Paul Torcellini.*

Q1: What is a Zero Net Energy Building?

Eley: The U.S. Department of Energy (DOE) came up with a common definition of a ZNE, with input from several ASHRAE members. For ZNE buildings "the sum of all energy that is delivered to the property line must be less than the energy that is exported from the property." All energy is included in the accounting, but energy used to charge electric vehicles driven off-site is considered "exported energy." DOE recommends using source energy as the currency for adding up energy from multiple fuels as it considers upstream impacts of electricity generation. While the common boundary for ZNE accounting is the property line (*Figure Q1*), the DOE "common definition" recognizes that the boundary can be extended to portfolios of buildings (same owner, different sites) and campuses (a contiguous group of buildings) and communities.

Gupta: ZNE has been fraught with numerous definitions by DOE, California and other agencies, all of whom consider it in the confines of a building/site where on-site demand is met by on-site generation. However, there are a couple of things to consider. ZNE is not a goal by itself. It is a mechanism or strategy to meet the high-level overarching goal of greenhouse gas (GHG) reduction. This has been lost in the dazzle of "zero."

Coming back to "What is a zero net energy building," I'd say it depends if it's grid connected or free standing. Any accounting of energy flow needs to be based in the context of the confines or boundaries that are drawn around the built environment, be it a building or a collection of buildings in a campus or microgrid. Also, current ZNE definitions are ambiguous about the net zero by design or by actual operation, which is another major aspect. So more questions than answers, unfortunately, but overall I'd say a ZNE building is one that contributes to the overarching goal of reducing the GHG emissions from the energy use in the built environment, through offsetting the energy use with clean energy generation within the boundary drawn for the context.

Torcellini: DOE, working with many stakeholders,

Bing Liu, P.E., Member ASHRAE, chief research engineer, Pacific Northwest National Laboratory, Richland, Wash.

Cathy Higgins, research director, New Buildings Institute, Portland, Ore.

Jessica Iplikci, senior program manager, new buildings, Energy Trust of Oregon, Portland, Ore.

Michael Rosenberg, Member ASHRAE, senior research engineer, Pacific Northwest National Laboratory, Richland, Wash.

solicited input on answering this question and established a common definition for a zero energy building as:

"An energy-efficient building, where on a source energy basis, the actual annual delivered energy is less than or equal to the on-site renewable exported energy."

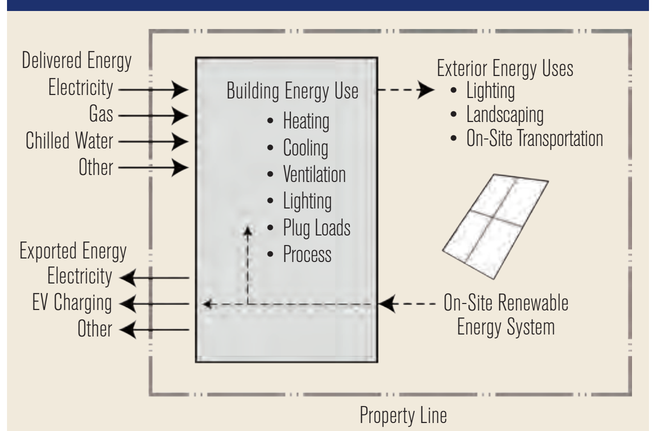
It is really about the balance—a building that uses so little energy that on-site renewable energy can provide for the energy needs. The focus is on the efficiency piece. When a building is so efficient that renewable energy could provide the energy, it is zero energy ready—ready for the renewable to be added.

While on this topic, the name discussion often comes up. Historically, those on the west coast use ZNE. The rest of the country tends to use NZE, and DOE along with others have dropped the word net and just calls them zero energy buildings. This is also the terminology being used in the next series of design guide documents put together by ASHRAE/IES/AIA/USGBC/DOE.

McHugh: On its broadest level, a ZNE building is one that lives within its ecological footprint. That has been interpreted to be one that is capable of being self-sufficient and consuming no more energy than is produced on site from renewable sources such as wind and solar.

The State of California has clearly defined what is a new zero energy low-rise residential building in California Green Building Standards (Title 24, part 11). This definition is based on long-term (30-year) projection of energy costs according to the time dependent valuation (TDV) methodology. The simulated energy consumption of HVAC and water heating loads must be at least 15% to 30% less than energy code compliance depending upon climate and whole building energy consumption, including plug loads, and must have an energy design rating (EDR) of zero or less. The energy design rating is normalized so

Q1 Site boundary for ZNE accounting. Solid arrows are considered in ZNE accounting.



Source: Design Professionals Guide to Zero Net-Energy Buildings, Island Press, 2016

that a building with an EDR rating of 100 is equivalent to a building designed to the 2006 IECC. Electricity exports are valued to be equivalent to electricity imports.

Q2: Can you help us understand the benefits of ZNE buildings?

Gupta: The benefits of ZNE buildings lie in their assisting with the overarching goal of reducing carbon emissions associated with the built environment. The collateral benefits are in the form of healthy and comfortable buildings for the occupants as well. The benefits of ZNE are more societal than personal, unless the current tariff and rate structures are updated to better reflect the economic benefits to the owners.

McHugh: ZNE buildings are very efficient buildings that also have a renewable energy system to offset imported energy. Very energy-efficient buildings are a good investment (utility savings less than financing cost), usually more comfortable with less drafts and fewer asymmetric radiant fields, and stable, and have higher quality lighting and well-commissioned controls. Besides the potential benefit of enhanced energy reliability that comes from having an on-site renewable energy source, the cost of the renewable energy system is effectively present-valuing the cost of energy consumption that historically has been on a pay-as-you-go basis. By front-loading the cost of energy inefficiency, the cost of the renewable energy system focuses the attention of the designer and the building owner to squeeze waste out of the building design.

For occupants and society, the ZNE building has the benefit of demonstrating it's possible to live within your energy footprint. This encourages hope for the future, and when combined with feedback such as an energy display, ZNE buildings can encourage occupant conservation to stay within the ZNE target of zero net consumption.

ZNE buildings reduce the environmental costs of energy production including criteria air pollutants, greenhouse gas emissions, emissions of toxics, toxic waste, thermal pollution, etc. Reducing these environmental effects reduces costs associated with: environmental mitigation, loss of habitat, reduced agricultural productivity, soiling and damage to surfaces, and the public health costs of illness and early death.

Torcellini: What we are seeing is that the energy-efficiency and setting efficiency goals is first. If done properly, the 50% to 70% reduction needed to achieve a zero energy building [will achieve the goal], by the definition. Often, it can be done at little or no cost increment if it is well established that this is the goal before design begins. While many of the benefits overlap with highly efficient buildings, the added benefit of "bragging rights" that you produce as much energy as you consume is important to many owners. If done correctly, they should provide superior comfort, daylighting, and the human factor benefits from this, simpler systems (needing less maintenance), better IAQ, and energy savings. If done correctly, they can also provide some level of resiliency against grid outages.

Liu: Building owners will benefit from ZNE buildings by setting a project goal that is outcome-driven and measurable. The project team will fully implement the integrated design strategies to maximize innovative design strategies. A ZNE building goal will also motivate the project team to bridge gaps among design, construction, and operation. ZNE buildings provide a healthy, comfortable built environment to occupants and inspire occupants to adapt their behaviors responding to ZNE buildings.

Higgins: ZNE buildings have distinct benefits to the occupant, owner, and society. For the occupant, ZNE buildings typically represent best-in-class design that integrates low-energy outcomes with improved environments. Specifically, daylight is increased as both a lighting reduction scheme and as a visual benefit to a larger proportion of the occupants, and thermal comfort is often improved due to the use of multiple HVAC systems applied as a mixed-mode strategy. ASHRAE's *High Performing Buildings* magazine published an extensive review of 90 high performance case studies and found an average of four HVAC technologies per building ("Evaluation of Factors Impacting EUI," Fall 2016). This reflects the "layered" approach to meeting occupant needs that, in turn, results in less energy use.

Q3: Can you help us understand what motivates owners to design and build ZNE buildings?

Iplikci: Motivating owners is the strategic question we have to ask and begin to answer as a community.

A major finding of Energy Trust's Path to Net Zero Pilot that led to expanded market delivery in 2011 was not only that significant energy goals were achieved for several building types, a great achievement, but that net zero goals were almost entirely possible using technologies available today, a clear signal to begin advancing the market along a path to net zero energy. Finding high-value energy strategies is a process, and will be in the early stages of transforming a market to adopt integrated energy-efficient design. What's great about net zero design is that it brings value to the whole building, something owners can appreciate, and brings the energy conversation to a new level. Net zero ties together many strategies, as many of us know, but does it in a way that's high-value and aligned with owners' needs.

There are many goals in a project, and net zero is not for everyone yet, but the first step is giving owners the option to pursue these goals. Some thoughts on a motivational approach to bring owners into the conversation early:

- On a project level, positioning net zero as part of the building, as opposed to an add-on, is key.
- Presenting a simplified EUI can spur the dialogue on what's possible and sets up the strategies.
- Depending on project goals and complexity, an early energy design meeting can be a low-cost way to add value to a project and take a deeper dive to identify top strategies.
- Positioning energy as a goal for the whole project is very motivating.

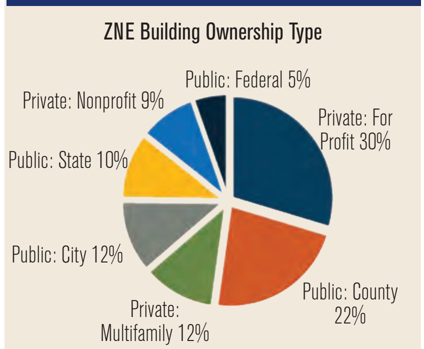
Advertisement formerly in this space.

Net zero buildings are increasingly contributing to newly built and renovated commercial construction. With these first buildings under way and more to come, now's the time to start communicating about these buildings—what makes them great places to live, work, and operate. Designing the nation's first net zero buildings will earn some well-deserved recognition for building developers and owners leading the way. We want to be part of their teams. Collectively, we can parlay these first wins into market momentum that gets more owners to ask for ZNE.

Torcellini: I do think owners are looking for ways to minimize their environmental footprint and reduce costs; there is a strong business case for building ZNE buildings.

Higgins: ZNE buildings offer the left, analytical, side of the brain a chance to stretch beyond a single metric of cost and assess the financial gains across multiple factors and time. Owners of ZNE building tend to look more at a return on investment and ancillary benefits and discard the absurd use of simple payback to determine their options. Many owners of today's ZNE buildings have identified and cited, often with the help of astute design teams, clear financial gains in one or more of the following areas: 1) reduced total construction cost due to integrated design (not universally true, but examples exist), 2) reduced operating costs, both in terms of energy bills and maintenance, 3) increased rent and leasing rates, 4) greater asset value of their real estate holding due to the pro forma calculation that considers operating costs and rental income, 5) decreased risk in the market for tenant attraction and in the regulatory environment to meet emerging codes and policies. Last, owners of ZNE buildings tend to be motivated by being ahead of the curve on technology and market trends and enjoy the public and corporate recognition that comes with a ZNE building. The trend in the past decade shows an increase in private sector adoption of ZNE (*Figure Q3*).

Q3 Private ownership of ZNE projects has doubled in two years, now comprising 50% of the buildings in NBI's Getting to Zero database (http://tinyurl.com/l4lpt5m).



Source: NBI 2016 Getting to Zero List and Update

Q4: What are some of the primary strategies, common technologies, and tools deployed in ZNE projects?

Liu: One key strategy at the pre-design stage is to fully understand where the energy will be used in a building. We can achieve it by studying the energy use signature of similar existing buildings. For example, several years ago Pacific Northwest National Laboratory (PNNL) teamed up with a financial institution to assist them in creating the first ZNE bank branch in Florida. We collaborated with the owner's IT department and metered the end uses of a similar bank branch in a different location. This metering data went against the traditional wisdom in many ways and redirected the project team to focus on the largest energy consumers, which were exterior lighting, signage, and plug loads. Tackling lighting and plug loads was then well understood after the end-use metering effort during the design phase.

Torcellini: The first goal is for owners to set zero energy as a goal and fix the building's budget. Find design and contractor teams that will deliver this product. There are many out there that can now deliver to this goal. From a strategy point of view, reduce plug loads, reduce lighting loads with daylighting and high efficiency lighting, improve the envelope (including appropriate amounts of glass), and design the HVAC system to match the remaining loads. These are broad strategies, and energy simulations should be used to guide the entire design process and help match the form and function of the building.

Higgins: The ZNE buildings all begin with a strong envelope design that combines some or all of the following: a) orientation, b) exterior shading, c) high insulation value and advanced materials, d) reduced window-to-wall ratios, and e) high-efficiency glazing. The technologies are then layered into this low heat gain/loss structure that has driven loads down through design methods first. For HVAC, in addition to traditional VAV, high-efficiency chillers, and air-source heat pumps, these buildings have a higher ratio of ground source heat pumps, radiant heating and cooling, dedicated outdoor air systems, natural ventilation, and both direct and indirect evaporative cooling. Electric lighting in ZNE buildings is commonly controlled through a triage approach of daylighting, occupancy, and hours. Lights default to off when a space is empty and are secondary to daylight to meet visual needs. Lamp types vary widely by space, and the full use of LEDs is still nascent, even in this advanced group of buildings, but LEDs are certainly emerging as an increasing part of design.

Advertisement formerly in this space.

As lighting load decreases due to increased efficiency of lamp/ballast technologies and the reduction in operating time due to controls, the importance of occupant-driven roles in getting to zero increases and can dominate energy use. Management of plug and miscellaneous electric loads is a common strategy for most ZNE building designers and operators. At the design stage, some buildings apply embedded plug load controls at the outlet and in operations. Recent research into controls in ZNE buildings* found almost 65% of ZNE buildings are addressing plug loads through one or more of three methods: 1) software (power management at the device or through the network), 2) hardware (plug strips, sensors, controls), and/or 3) people (prompts, campaigns, displays, competitions).

Q5: A decade ago California set ambitious goals around ZNE, i.e., all newly constructed residential buildings are to be ZNE by the year 2020 and commercial buildings by 2030. Can you provide an overview of the progress, how we arrive there, and some lessons learned?

Eley: The California Energy Commission (CEC) has the goal to require that all low-rise residential buildings be zero net energy by 2020, but at the same time it's enabling legislation (the Warren Alquist Act) that requires that its building standards "be cost-effective when taken in their entirety and when amortized over the economic life of the structure compared with historic practice." The challenge is to meet the ZNE goal while passing the cost-effectiveness test required by the legislature.

The CEC has always taken a societal perspective with regard to cost-effectiveness, showing that the standards are cost-effective for the people of California as opposed to individual investors. As a result, California uses a type of real-time pricing in its cost-effectiveness analysis called time dependent valuation (TDV). When TDV was first implemented, it gave more credit to renewable energy production since it aligned with higher real-time prices on hot summer afternoons. However, as California has brought more renewable energy from solar onto the grid, the TDV peak has shifted from the afternoon to the early evening, which has had a negative impact on the cost-effectiveness of solar. In addition, the CEC has always encouraged the use of gas for space heating and water heating in homes, and achieving ZNE requires that homes be a net exporter of electricity. Under the current tariff structures, the excess energy is credited at a lower rate, further eroding the cost-effectiveness of ZNE.

With these challenges, the current plan is for the 2020 California energy standards to require enough PV to offset the electricity in a gas home, but not enough to achieve ZNE. For all-electric homes, the PV required would be the same as if the home had gas space and water heating.

McHugh: In 2006, the California legislature passed AB 32, the California Global Warming Solutions Act, which committed California to limit its greenhouse gas emissions to 1990 levels by 2020, while having 40% more people and a higher standard of living. In 2008 the California Public Utilities Commission (CPUC) developed their Long Term Energy Efficiency Strategic Plan, which included the 2020 and 2030 ZNE goals. This plan was supported by the California Air Resources Board and the California Energy Commission. These goals built upon the structure of the 2030 Challenge developed by Ed Mazria and others and was endorsed by the American Institute of Architects. This ZNE goal moved from being an aspirational goal to an actionable goal as a number of studies showed that zero net energy was technically achievable for about 75% of the construction stock in California and that renewable energy was cost-effective. Given the amount of support at all levels of California government, the 2019 Title 24 building energy-efficiency codes appears to be on track toward mostly achieving the goal for all new low-rise residential construction being ZNE by 2020.

This "mostly ZNE" residential energy code has a number of benefits:

- Photovoltaic energy systems are installed on every rooftop in entire subdivisions. This should drive the cost of renewables down, and reduce the amount of land area required for renewable energy production.
- Federal appliance efficiency standards preempt states from requiring higher levels of HVAC and DHW efficiency in the building code than the minimum federal standards. However, to reduce the size and cost of the renewable energy system, builders can voluntarily increase equipment efficiency. This creates a huge market opportunity for high efficiency equipment.
- All forms of energy efficiency are incentivized by size reductions in the required PV system needed for code compliance. Unlike historic practice, energy inefficiency is not borne over time through higher energy bills. Rather, a larger up-front payment for a larger solar system more readily exposes the impact of inefficient building design.

* Higgins. C., et al. 2015. "Zero Net Energy Building Controls: Characteristics, Energy Impacts and Lessons Learned." NBI and CABA.

Advertisement formerly in this space.

One of the key lessons learned is that it is not enough to have an aspirational goal; it is important to have a step-by-step tactical plan for achieving the goal. Thus, for each building code cycle and for each appliance standard proceeding, there were specific technologies targeted to reduce residential low-rise building energy consumption. Prior to proposing these measures for inclusion into the energy-efficiency standards, the technologies of interest were characterized in terms of their energy impact, their costs, their compatibility with other building components, and their market share. Demonstration projects and field surveys help ensure that the code change is feasible and does not have unintended consequences.

Q6: Improving building energy efficiency and deploying PVs were identified as the primary tools to achieve the ZNE goals a decade ago. Given the advancement of technologies and better understanding of individual PV's impact with grid harmonization, should we rethink our strategy?

Eley: I believe that ZNE is still a goal we should pursue in all our buildings. It's something that each of us as engineers and architects can pursue to address the staggering environmental problems we face. We can pursue this goal no matter who is running the government or the budget allocation to EPA and DOE. However, ZNE by itself is not enough; our ZNE buildings need to place a minimal burden on the grid, and the grid needs to be modernized to accommodate a growing number of ZNE buildings. The goal of "grid harmonization" presents opportunities on both sides of the meter. Buildings should implement renewable energy only after the maximum energy efficiency is achieved and incorporate controls and storage. Utilities should increase interconnectivity, provide the right price signals, incorporate storage, and treat each customer as both a supplier and consumer of electricity.

McHugh: There are plans to add large central storage systems as well as distributed storage on the grid. In addition, decommissioning large fixed output power plants will free up existing storage on the grid to support renewable energy sources.

Since 2010, most new California nonresidential buildings and most newly added air conditioners to nonresidential buildings have been required to have demand responsive controls. Since 2014 demand responsive lighting has been required for new buildings over 10,000 ft^2 (929 m^2). So far this capability has not been fully enabled or exercised.

With the time dependent valuation (TDV) of energy, the California energy code provides compliance incentives for thermal storage. However, there are not currently simulation rules for providing credit for battery storage or for hot water storage. Recently, the TDV values have shifted to account for all the renewables on the grid, and they will likely shift more as the generation mix changes.

Thus, the capabilities of the supply side and consumer side of the meter are evolving to respond to the widespread deployment of renewables. This creates opportunities for new business models and technologies and will influence the definition and implementation of ZNE buildings in the future.

Torcellini: Efficiency is still the primary driver. As the technologies improve, there are more and more ways to achieve the EUI targets needed to achieve success. The cost decrease in PV systems makes the supply side achievable for many. For example, the low cost of LED and the high efficiency still make daylighting important, but perhaps you don't have to try to get to 100% of the space daylit. You can mix these two technologies and still achieve the EUI goal, where 10 years ago you needed more daylighting to achieve the goal with older lighting technologies. In many utilities, there is still lots of room for growth of PV on the grid.

Q7: ZNE is still a relatively new movement after decades of effort. What do you think are the major barriers to drive market adoption of ZNE buildings? How do we turn the buzz surrounding ZNE into real advances on the ground?

Torcellini: I think the biggest barrier is that many are not aware of the incredible improvements in energy efficiency and the new generations of equipment. This mixed with a sharp decrease in the cost of PV have made the cost hurdle almost nonexistent. But many people looked at this five to 10 years ago and could not make the business case and have not revisited it. ASHRAE/AIA/IES/USGBC and DOE are currently working on the new series of Advanced Energy Design Guides targeted at zero energy. First is K–12 schools. More case studies are coming every day. This will also help.

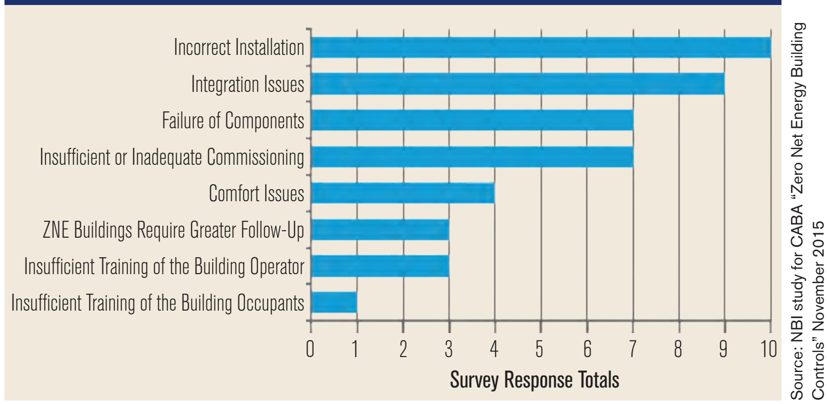
Higgins: I think the "buzz" comes from the market leaders who are showing both technical and financial success in constructing, operating, and managing these buildings. No one likes the feeling of being left behind in market trends or in financial opportunities, and the greater we can broadcast the business side from these leaders,

Advertisement formerly in this space.

the stronger the pull to a larger set of practitioners and owners to make ZNE business-as-usual.

Risk aversion is one part of the ZNE story in terms of meeting current or pending climate or carbon policies and in meeting best practice work environments for today's knowledge class. We're too focused on the "energy and environment" story and singing to the choir when it's the health and financial benefits—told in a stronger pro forma real estate format with life-cycle and asset value considerations—that resonate and motivate more widely. Getting owners to ask for performance outcomes will also help drive the market and accelerate practitioners' delivery of ZNE buildings. That's a new model, but there are solicitation and contract templates for new projects† as guidance.

Q8 Reasons for design team follow-up on ZNE buildings.



The gap between design and operations remains a longstanding gap that needs to be solved as more of the energy outcomes rely on post-construction factors. Operators tell me they feel abandoned with new buildings, technologies, controls (especially), and little guidance on operational optimization. While the design intent is good, the field results are often sub-performance, or [lead to] disabling of confusing or frustrating features. Operators don't want hundreds of new data points/sensors that tell them thousands of one-minute interval data. They want easily displayed and clear key performance indicators that are correctly providing the building metrics.

Smaller buildings, those under 50,000 ft^2 (4645 m^2) that comprise 94% of U.S. buildings and nearly 50% of U.S. commercial floor space (CBECS), typically lack an on-site or full-time operator, so controls need to be clear to the occupant and have defaults to off. Designers want reduced call backs and outcomes that more closely match their models. Increasing the role of the design team through post-occupancy and increasing contractor, operator, and occupant understanding of the goals and the systems in ZNE buildings would go a long way. Thankfully, ZNE is reaching a small but helpful mass of design firms, public and private owners, and policies that will be strong contributors to growing the movement.

Q8: Do building energy codes have a role to play in facilitating the move to ZNE buildings? If so, what needs to be done to achieve it?

Gupta: Building energy codes can play a role in facilitating the move to ZNE by adopting measures that are cost-effective, and there are no market hurdles to their adoption in the mainstream of building practice. Codes by design are a mechanism to bring up the bottom and set a base. Therefore, the role of energy codes is more to lay the groundwork for the path to ZNE rather than adopt ZNE as a code. By the time ZNE gets codified, it will imply that it has met all the tests of cost-effectiveness, so the ZNE code would be the last thing that happens in terms of ZNE adoption by design.

The second role for codes is the potential of an ongoing touch point with the buildings in what is termed as outcome based codes. Outcome based codes imply ongoing monitoring and are enforced past the design and construction of the building and go into occupancy and operations. This, however, is a much more involved compliance and enforcement proposition and hence more challenging. But with more technology and electronic touch points in the built environment, it is increasingly becoming a feasible option. This is where the net zero in building operation will truly be measured and verified and can have the intended GHG reduction impact.

McHugh: Energy efficiency: Energy-efficiency codes and state policies have a significant impact on the adoption of ZNE building design principles.

As energy consumption by lighting and HVAC loads declines, the importance of plug and process loads increase as we approach zero. Appliance standards have a tremendous role to play in decreasing both active power and standby power of devices found in buildings. Some energy codes have a well-defined set of rules on how to simulate building performance. These rules help the

† NREL. 2014. "Cost Controls for ZNE Buildings: High-Performance Design and Construction on a Budget."

designer predict the building assets that are capable of being ZNE. However, these simulation tools can also be a barrier if they do not have enough capabilities to simulate advanced building systems. This points to improving the underlying simulation engine as well as to the performance method rule sets.

Energy codes or building rating methods can create a legal, unambiguous definition for "ZNE building," so the term has value and is not subject to "green washing." Without assurance that the ZNE definition is valid, skilled designers, builders, and real estate management companies have a more difficult time convincing their clients the value of their ZNE building. Building codes or legislation can remove barriers to ZNEs such as those associated with zoning requirements or covenants, conditions and restrictions (CCRs) that limit the use of light colored "cool roofs" or solar panels. Public utility commission or electric board grid net energy metering rates have a significant impact on the cost-effectiveness of on-site renewable energy systems, and thus ZNE buildings.

Rosenberg: Energy codes can definitely play a role in facilitating ZNE buildings, and in some respects they already have. As new energy saving technologies and strategies are codified, those practitioners and building owners on the leading edge strive for even greater performance. Whether it is for financial incentives (like tax credits or utility incentives), a plaque (like USGBC's LEED Rating System), program requirements (like the federal building mandates), or for altruistic reasons, there are always those willing to push beyond the minimum cost-effective requirements in energy codes. As those leading edge technologies and strategies mature, they become cost-effective and reliable enough to mandate in new codes, and the process repeats itself, all the time moving the bar of minimum code compliance closer to ZNE.

However, if the codes themselves are to eventually mandate ZNE buildings, there needs to be some basic changes in their structure. First, more energy end uses must come under the purview of energy codes. Today's energy codes focus mainly on building systems and components providing comfort and amenities for occupants that are directly under control of design and construction teams. Other energy end uses are often ignored although they make up a significant portion of building energy use.

Recent codes have added requirements for previously unregulated components such as elevators, transformers, commercial refrigeration systems, and computer room cooling, yet there are still many energy using systems and components in buildings that are unregulated. Included in the unregulated category are industrial and process equipment, miscellaneous plug loads, cooking equipment, decorative lighting, and pumping for water features. To achieve ZNE building codes, those energy end uses and others will need to be covered by some type of building energy regulations.

Second, there needs to be a switch from individual prescriptive requirements to an energy performance basis. Focusing on individual components ignores their interactions with other building systems and building-specific environmental conditions, making it impossible to realize the energy savings potential of a complete building. In contrast, focusing on the energy performance of the whole building and its environment as an integrated system unlocks the ability to achieve much greater savings in a cost-effective manner. That performance based focus could include a greater reliance on simulation to demonstrate design performance (as is an option in current codes), real energy outcome based performance (where utility bills provide proof of performance), or even better, a combination of both of these approaches.

Q9: Can you share the real-world experiences and challenges to live, operate, and maintain ZNE buildings?

Torcellini: Like any building, it takes work to make it perform. Real data must be collected and issues identified to keep the performance up to design levels. Design teams need to be realistic about how the building will be operated and allow for some margin of error. PV systems never put out quite as much power as you think, and buildings always use just a little more energy. Create a buffer.

When something breaks, having good data and a performance reference points helps to maintain the building at peak performance. This is important. I think many buildings run with one flat tire all the time, and no one really pays attention. If done correctly, these buildings should be just as easy or easier to maintain than any other building.

Many people are proud to be in a zero energy building. Often occupants will help make it happen and will become the champions. I have seen this in our own NREL zero energy office building and in zero energy schools. Occupants are a valuable part of getting to zero, and they should be recognized for their role. In NREL's building staff love the views, natural ventilation, high degree of comfort, open atmosphere—all of which and many other attributes contribute to a wonderful working space. ■