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NET ZERO ENERGY: TECHNOLOGIES AND APPROACHES TO TRANSFORM THE BUILT ENVIRONMENT

An Overview

Issue Brief

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INTRODUCTION

It will be challenging – but it may become economically and technically feasible – to achieve net zero energy in a variety of new and existing commercial buildings. The basic steps are clear: make the building as energy efficient as possible through integrated design and the use of energy-saving technologies, add renewable energy on site and through the electrical grid, and ensure optimal building performance over time.

Increasingly, policy and the market alike are driving building owners to focus on sustainability, livability and productivity. As energy prices and energy security concerns increase, and as information technology allows better performance tracking, building owners and occupants are seeking more information on the performance of their buildings. The net zero energy building is an idea that has captured technologists, architects and governments around the world. But is it possible?

There have been step changes in differentiating buildings over the years. Significant drivers of change include advanced energy codes, the U.S. EPA ENERGY STAR buildings program, and most recently, the U.S. Green Building Council (USGBC) Leadership in Energy and Environment (LEED) program. With European and U.S. governments committing to net zero or near zero energy buildings, innovative designs and implementation strategies are emerging that could transform buildings – and the experience of the people in them. The lessons from these buildings will jump-start the transformation of the commercial sector as well.

In time, net zero status may not be reserved for a few demonstration projects using expensive emerging technologies. It will be possible to achieve significant energy savings at competitive costs, using readily available, commercially main-stream materials, equipment and systems. Energy use is minimized and then the balance needs to be matched with cost effective renewable energy. Finally, since occupant behavior and the growth in plug loads in buildings may influence the potential certification or validation of a building's net zero status – and certainly the economics – occupant engagement and building performance will be critical.

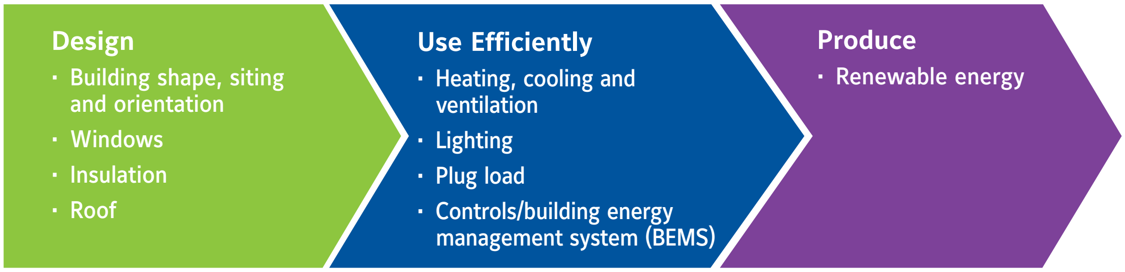
A Change by Design: How USGBC's LEED Program created the market

In 2000, LEED-certified green buildings were rare: Conventional wisdom said the cost premium was too high. Today, buildings built to LEED standards are common and certification is almost the norm. By the end of 2010, 7,704 new and existing commercial buildings in the United States had some form of LEED certification and one third of new U.S. commercial building construction starts are LEED-certified.

Construction cost data reveals that buildings rated at the LEED Silver level cost about the same as traditional construction per square foot. LEED serves as an example of innovation in the construction market and represents a broader trend toward smarter energy management and greater transparency in the building market around lifecycle energy costs.

The scale of the challenge will be different, depending on the building type, size and location. But, all buildings share the same levers (see Figure 1) that will enable net zero energy buildings.

Figure 1



Sources: ASHRAE, Internal JCI analysis

How can net zero energy buildings become standard, routine, and available at market competitive prices?

EARLY EXPERIENCE IN NET ZERO

There are relatively few net zero buildings in the U.S. today – although more are under construction and on the drawing boards. Many are small projects (generally less than 10,000 square feet) and were designed as prototypes to demonstrate this new approach to building design and technology. Most net zero buildings today include unique and sometimes exotic features. Creators of these buildings are innovators, early adopters, holistic thinkers, and organizations such as the military that are driven by a desire to be energy self-sufficient.

Because cost is currently a barrier in implementing new approaches and combining technologies, policymakers are pushing the market with incentives and mandates. The Energy Independence and Security Act (EISA) of 2007, for example, requires new U.S. federal government buildings to be net zero energy by 2030, and *all* federal buildings to be net zero energy by 2050. It also authorizes formation of an industry consortium to develop technologies, practices, and policies that help achieve similar goals for commercial buildings.

On the state level, California has committed to making all new commercial buildings and 50 percent of existing commercial buildings net zero by 2030. State officials have calculated that commercial buildings must reduce energy consumption by 60 to 70 percent to reach the net zero buildings goal.[1]

National Renewable Energy Laboratory, Golden, Colorado, USA[2]

At 358,000 square feet, NREL has the largest net zero building in the US today.

Features that made Net Zero possible:

1. Building orientation
2. Labyrinth thermal storage
3. Transpired solar collectors
4. Daylighting
5. Triple-glazed, operable windows with individual sunshades
6. Precast concrete insulated panels
7. Radiant heating and cooling

[1] CA Energy Efficiency Strategic Plan, NZE Commercial Buildings

[2] http://www.nrel.gov/sustainable_nrel/pdfs/48943.pdf

The European Union (EU) also has early experience with net zero energy buildings. There, all new buildings are to be "nearly" zero energy by 2020, and buildings owned and occupied by public authorities must reach this goal by 2018.[3]

As these and other examples demonstrate, after optimizing energy use, getting to the goal economically means taking a "reduce, then produce" approach: driving down the building's energy demand as far as possible, then filling the remainder with renewable power generated on the property or purchased on the market.

WWF Headquarters, The Netherlands[4]

This building is a testament to how an existing building – in this case a former agricultural laboratory dating back to the 1950s – can be transformed into an energy- and carbon-neutral office environment.

- 3,800 square meters
- Building envelope transformation
- On-site renewables
- High-performance insulation

NEW BUILDINGS: FOCUSING ON BUILDING DESIGN

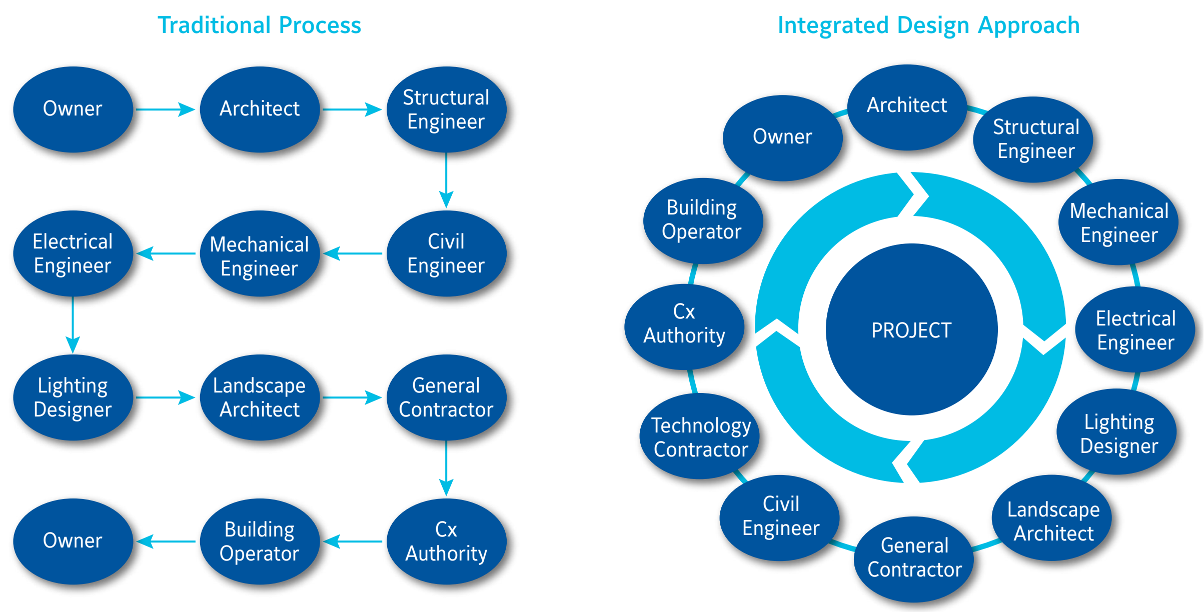
Net zero commercial buildings will require new building design approaches. Integrated design offers an opportunity to bring together a variety of specialists and building users to jointly define the buildings attributes, goals and features. In this approach, representatives from a variety of disciplines get involved from the start, share ideas, and explore how to meet the goals for the building. The goal of reducing energy demand in pursuit of net zero informs every decision on building shape, materials, equipment and features. The challenge facing designers of net or near zero energy buildings is to lower building energy demand enough so that building-integrated or purchased renewable energy can provide the remaining power – and do so economically.

The integrated design phase may involve more people, take longer and cost more, but it leads to a more cost-effective project in total that is more likely to achieve the ultimate aim. In contrast, the traditional design process is sequential: The architects offer a few options to the building owner based on the owner's objectives, and there is little broad engagement or brainstorming around how to meet core objectives at the outset. Generally, ideas are offered through a linear process, rather than up front. This means decisions made at the start may determine the outcome, without the benefit of ideas from other experts who consulted only later in the process.

[3] Agreed in 2009 and 2010 as part of the negotiations over the EU's revised framework building efficiency law – the Energy Performance of Buildings Directive (EPBD) – the term 'nearly' reflects a political compromise agreed between supporters of net zero energy targets and proponents of a less ambitious target. While the precise definition of nearly zero will be established by individual EU countries over the course of the next year, in practice the term means that a small amount of non renewable energy use will be permitted in buildings carrying a nearly zero energy distinction.

[4] For more information please visit: http://rau.eu/en/category/projecten/kantoor/

Figure 2: Shifting the Design Construction Paradigm to the Integrated Design Approach



It turns out that smart design does more than any other single factor toward reaching net zero. Among beneficial design decisions:

- A slender, rectangular building oriented east-west makes optimal use of daylighting – electric lights may be unnecessary during daytime hours.
- Efficient windows and insulation can reduce heating and cooling demand.
- Operating windows can provide natural ventilation and some cooling.
- Good decisions on wall thickness, mass and materials can help the building heat and cool more efficiently.
- Less heating and cooling load enables use of smaller-capacity equipment for heating and cooling. However, there may be an increase in air handlers and fans to deal with fresh air requirements.

In addition to design, the following technologies and practices help optimize energy performance and can be included in new commercial buildings:

- HVAC
  - Improved building energy management systems.
  - The most efficient available HVAC equipment.
  - Radiant heating and cooling.
  - Geothermal heat pumps.
- Lighting
  - Phase-out of incandescent lighting.
  - Replacement of T12 fluorescent fixtures with more efficient T5s and T8s
  - Displacement of fluorescent lighting by light-emitting diodes (LEDs).

Beyond those improvements, plug loads become proportionally more important as other sources of demand decline. Here, occupancy sensors can be used to shut off outlets when spaces are vacant. In addition, each outlet could have its own IP address and communicate with the building energy management system, enabling a high degree of control.

While building energy intensity varies with function, the average energy demand in existing commercial buildings in the U.S. is 91 kBtu/ft²/yr, according to the latest U.S. Department of Energy Commercial Buildings Energy Consumption Survey (CBECS). If constructed according to more recent energy efficiency codes, an average new commercial building would have an energy intensity of 70.7 kBtu/ft²/yr.[5] Further analysis shows that with help from newer technologies now in the development pipeline, average new commercial building energy demand could be reduced to 36.7 kBtu/ft²/yr by 2030 – nearly 50 percent lower than is generally achievable today.

A technology adoption and economic model identified technologies seen as potentially important energy efficiency drivers in the next two decades. The technologies modeled were existing premium products or technologies just commercializing – including some that are costly today but likely to see price declines in the future. Figure 3 estimated the year in which each item would reach a four-year payback from energy savings: a point where the commercial sector should begin to accept them.

[5] Griffith, B, "Assessment of the Technological Potential for Achieving Net Zero Energy Buildings in the Commercial Sector, National Renewable Energy Laboratory, 2007.

[6] System comprised of demand response capability, energy performance monitoring/ analytics, and integration of component-level controls and sensors

[7] As primary method of building skeleton insulation.

Figure 3: Total New Commercial Building Energy Use per Year

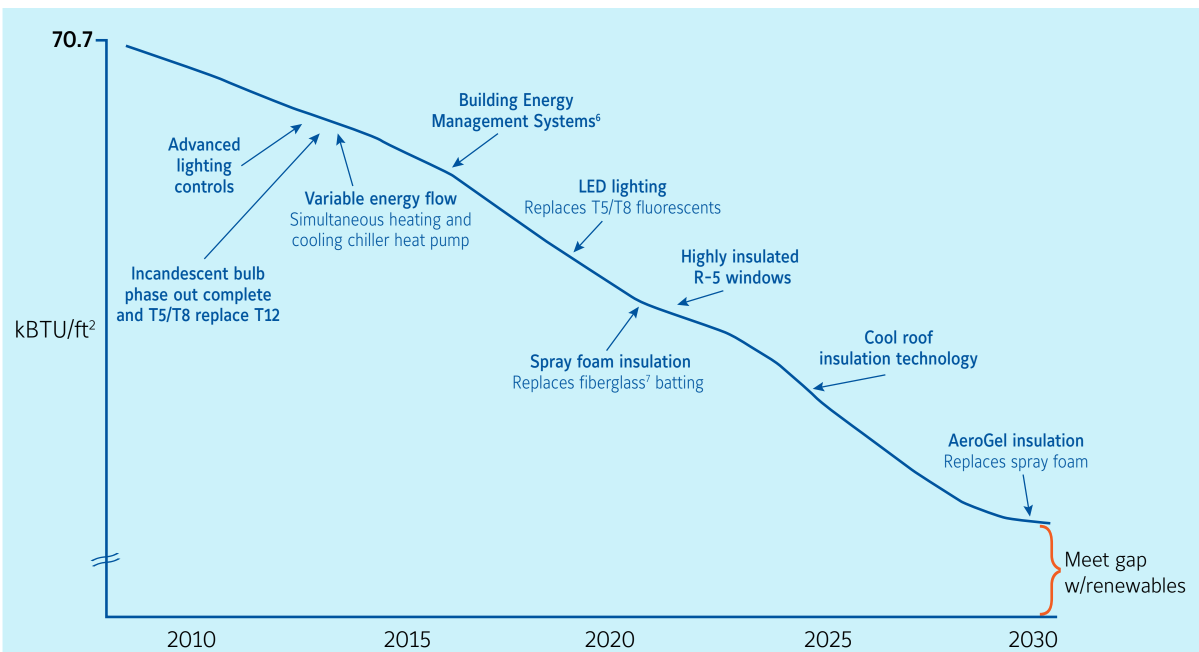
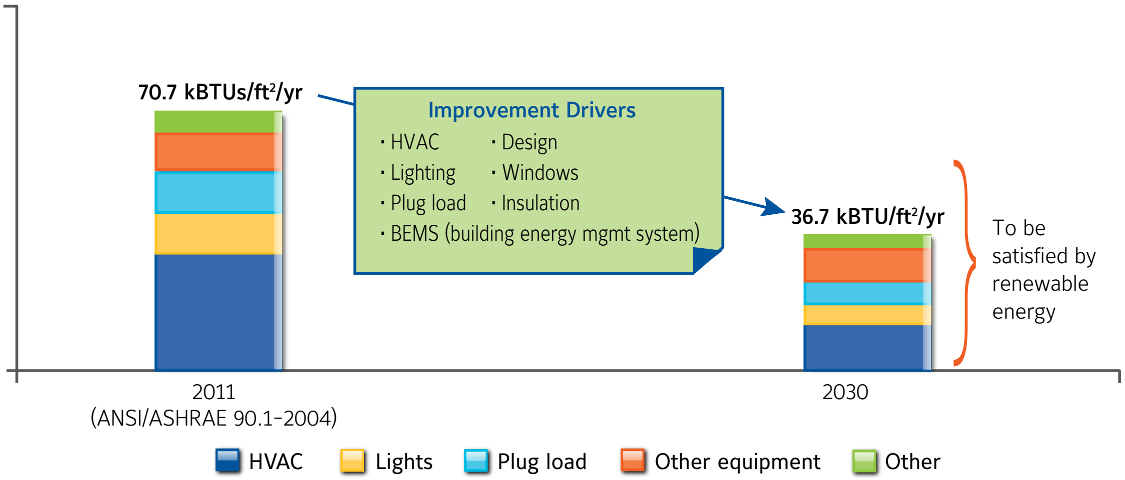


Figure 4 shows the contribution each building feature makes to the energy intensity of new buildings today, along with the potential contribution newer technologies can make toward reducing that energy intensity by nearly 50 percent by 2030.

Figure 4: Energy Intensity of New Commercial Buildings Can Be Cut by Nearly 50% on Average (kBtu/ft²/yr)



One critical influence on new commercial building design is the energy code. In seeking to achieve net zero energy over time, codes and standards help drive change. The primary U.S. energy standard governing new commercial construction is ASHRAE/ANSI/IES Standard 90.1. That standard is updated every few years (most recently in 2010), each time requiring greater efficiency. Each new standard eventually becomes embodied in local building codes. If constructed according to the 2004 standard, an average new commercial building would have an energy intensity of 70.7 kBtu/ft²/yr. In the U.S. context, codes are implemented and enforced at a local level, therefore the actual pace of change in code adoption varies significantly.

Figure 4a: Building Energy Demand

Average building 2011	91 kBTU/ft²/yr
ASHRAE 90.1 implementation	70.1 kBTU/ft²/yr
2030 available technologies	36.7 kBTU/ft²/yr

Source: Griffith, B "Assessment of the Technical Potential for Achieving Net-Zero Energy Buildings in the Commercial Sector," NREL, 2007.

OPPORTUNITIES IN EXISTING BUILDINGS

In 2030, two thirds of commercial buildings in the United States will be the same buildings that exist today. Achieving net zero energy in existing building stock is challenging – it requires not only installation of new technology, but a shift in the decisions made during every "compelling event" in a building's life.

Once a building has been designed and situated at a particular location, some of its energy demand may be locked in. For example, its direction of exposure, window-to-wall ratios, and other structural features cannot change. Still, most other features that determine energy usage will need to be replaced at some point in the building's life. A building owner may consider the following types of actions in an existing structure:

1. **Light, periodic system upgrades:** Some systems are economical to replace immediately as part of a typical retrofit. These opportunities include optimizing lighting, installing occupancy sensors, and applying other technologies that can be upgraded with relatively high frequency and with minimal disruption to the building occupants.

2. **Strategic investments in efficiency:** Other systems are more economical to replace when there is a "compelling event" that offers opportunities for significant upgrades or introduction of new technologies and tools. For example, the failure of an existing chiller provides an opportunity to re-examine how heat and cool air are provided to the building. As part of a major investment in the building, it is feasible to consider different technologies with lower energy demand. For example, a chiller might be replaced in part by a ground-source heat pump. Another 'compelling event' might be the arrival of a new tenant and the opportunity to maximize energy efficiency during the tenant build-out.
3. **Major renovations:** The biggest 'compelling event' in a building's life is a major renovation. Approximately two percent of all buildings undergo a major renovation each year. The renovation cycle presents a tremendous opportunity to focus on net zero goals.

In existing commercial buildings in the U.S., a typical retrofit today achieves energy reductions of 10 to 20 percent. But a retrofit done today at the time of a major building renovation can achieve 30 to 40 percent energy savings. Analysis shows that with anticipated improvements in technology and its costs, major renovations by 2030 may yield even greater savings.

The following technologies and practices help optimize energy performance and can be installed as part of either a light, periodic upgrade or a strategic investment opportunity:

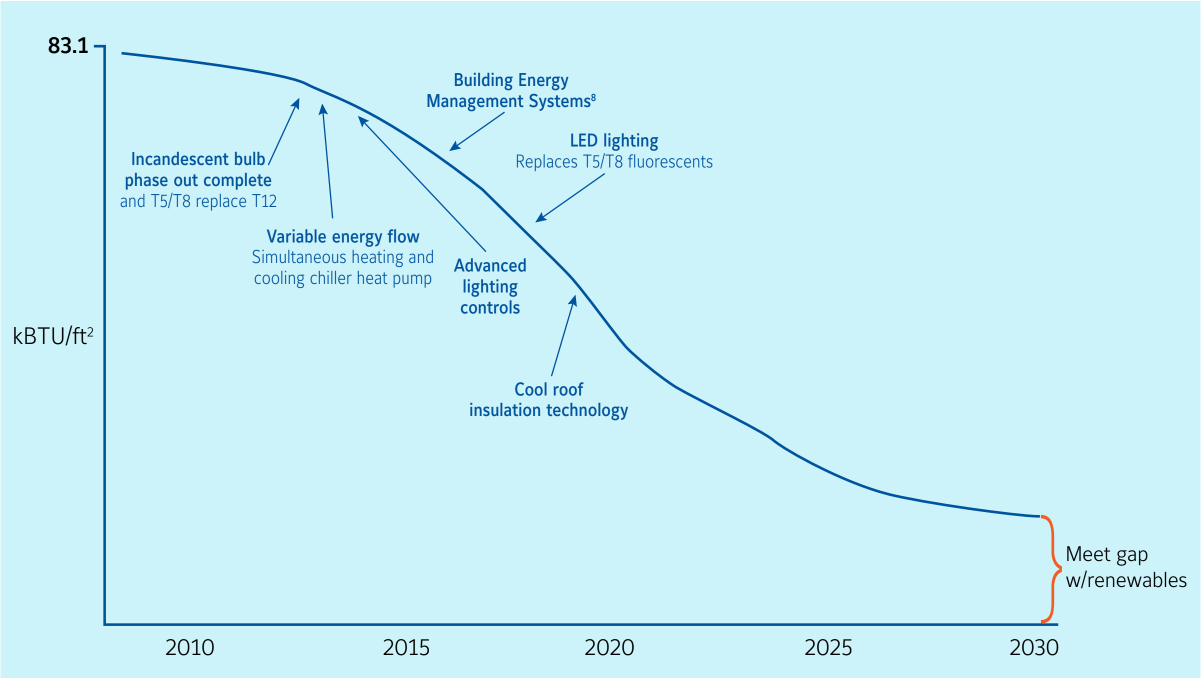
- Improve Heating, Ventilation and Air Conditioning systems:
  - Retrocommission the building: optimize all building systems, updating thermostat set-points, rebalancing the air-handling system, and tuning up mechanical equipment so that the system performs as originally designed.
  - Install digital controls infrastructure, smarter energy management systems and advanced energy analytics.
  - Enable grid communication and automation for demand response.
  - Upgrade/modernize new equipment as needed.
  - Add geothermal heat pumps
- Upgrade lighting
  - Install efficient lighting.
  - Improve lighting controls.
  - Use occupancy and daylight sensors.
  - Maximize use of day-lighting.
- Revise operation and maintenance practices.
- Minimize plug loads.
- Design and implement education programs encourage occupants to adopt more energy-efficient behavior (for example, provide power strips and ask occupants to switch off to eliminate vampire loads).

Major renovations offer an economical opportunity to install technologies that improve the energy profile of the building envelope and significantly improve the heating and cooling systems. Technologies in this category include:

- Cool roof replacements.
- Insulation and radiant barriers in the walls.
- New, high efficiency windows.
- Radiant heating and cooling systems.

Figure 5 illustrates the drop in energy consumption drop that can be expected cby deploying leading-edge technologies and introducing them at points in time where they become more cost-effective. This analysis assumes market adoption would begin when the simple payback approaches four years. The figure does not chart the structural improvements that would be made in a major renovation.

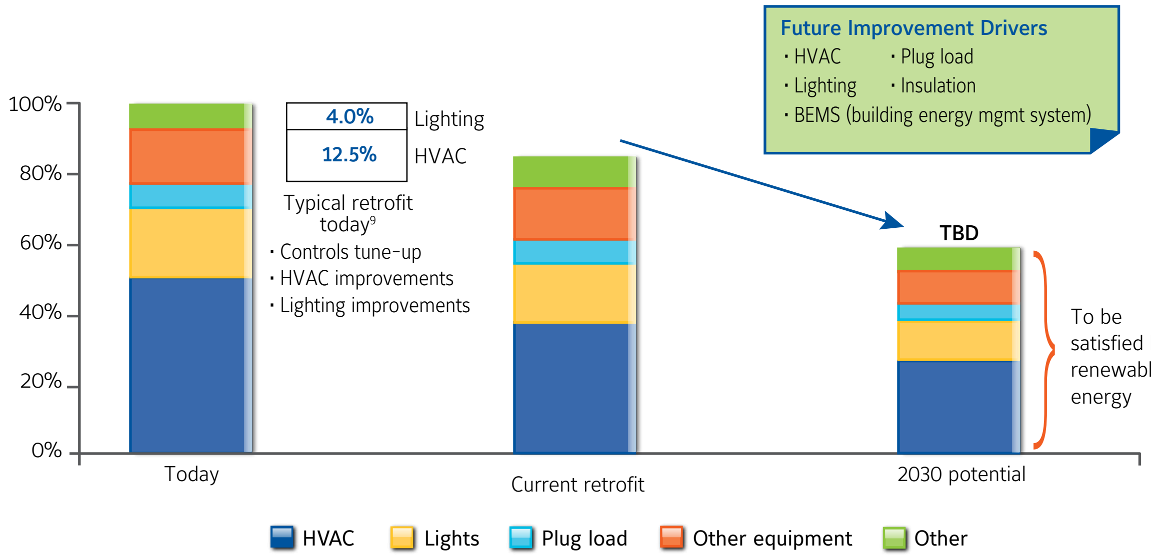
Figure 5: Total Building Energy Use per Year After a Current Retrofit



[8] System comprised of demand response capability, energy performance monitoring/analytics, and integration of component-level controls and sensors.

Figure 6 more closely examines the energy reductions required to meet zero energy targets. This analysis shows a more detailed breakdown of reductions from traditional technologies and systems and contrasts a retrofit approach of today with the energy reductions that will be needed from the systems of tomorrow.

Figure 6: Impact of Key Technologies on Energy Consumption (kBtu/ft²/yr)



[9] Institute for Building Efficiency. Controls tune-up saves 10% of HVAC energy & includes setpoint/ schedule adjustments, correct economizer functionality, hot water reset, boiler stage control/ sequencing, adjust outside air settings/DCV & VAV control optimization/static pressure reset. HVAC improvements save 15% of HVAC energy & include test and balance, CPO, energy recovery, steam trap repair, variable speed drives, repair/recalibrate sensors/ actuators, evaporative precooling of air-cooled condensers, data center air-flow management & CRAC control. Lighting improvements save 20% of lighting energy & include fixture retrofits, sensors/ controls and delamping.

[10] Voss, Karsten et al. *From Low Energy to Net Zero Energy Buildings: Status and Perspectives.* Journal of Green Building, 2011. Volume 6, Number 1

Even after the most ambitious energy reductions have been pursued in an existing building, reaching net zero energy is likely to require substantially more renewable energy. On-site renewable generation may not always be achievable, raising the question of whether renewable energy needs to come from a nearby or community source.

POLICY AND MARKET DRIVERS

While case studies have clearly shown that net zero energy buildings can be createded using existing technologies and practices, most experts agree that a broad-scale shift toward net zero energy buildings will require clear policy frameworks and potentially significant adjustments to prevailing market structures.

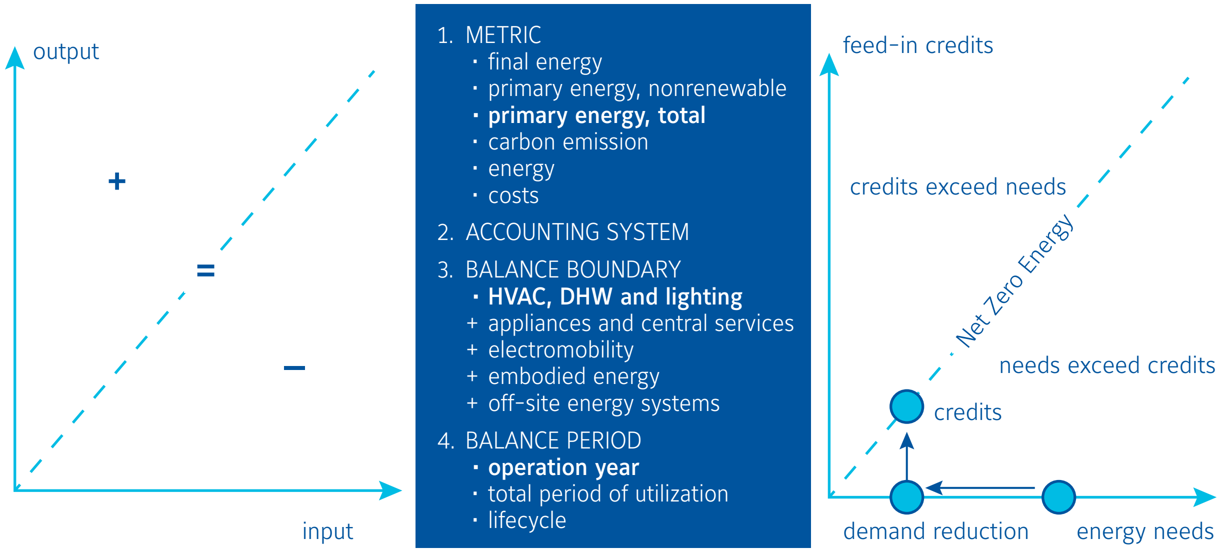
To date, the basic definitions, boundary conditions, measurement metrics and other components for a robust net zero regulatory framework are either incomplete or missing in most, if not all, countries.[10] In the EU, for example, member countries are required within the next year to two years to elaborate definitions for "nearly" zero energy using primary energy as an indicator. EU countries must also elaborate midterm (2015) goals for achieving their agreed nearly zero energy targets (2018 for all new public buildings and 2020 for all new buildings), while laying out policies and measures to achieve nearly zero energy in existing buildings.

Researchers working as part of an International Energy Agency (IEA) program on net zero energy buildings suggest that an appropriate framework for driving net zero energy buildings could feature:

- Primary energy use reduction as the main metric for assessing progress.
- HVAC, domestic hot water and lighting as technological boundary conditions.
- The operation year as the balance period, meaning that a net zero energy balance (energy inputs versus energy outputs) may not be achievable every month of the year, but rather over the course of one year.

This framework is outlined graphically in Figure 7.

Figure 7: Proposed Net Zero Regulatory Framework



Source: Voss et al, 2011.

National and international policymakers who wish to support the broad diffusion of net and near zero energy buildings will need to determine what kind of regulatory framework is most appropriate for their jurisdictions.

Meanwhile, market structures – both for public markets and in private-sector settings – are likely to require significant adjustments for net zero energy buildings to achieve scale. In some case procurement rules or norms can limit the scope of services that public entities can access. Energy efficiency and renewable energy service providers may not be able to deliver the kind of integrated (or bundled) efficiency and renewable energy offerings needed to achieve net zero buildings cost-effectively. It will also be necessary to address uncertainties around performance measurement and certification, lack of available financing instruments, insufficient information, missing economic incentives, and a range of other issues if net zero energy buildings are to move into the mainstream.

CONCLUSION: SCOPING THE PATH TO A NET ZERO BUILT ENVIRONMENT

Market precedents and technology trends in building efficiency suggest that transformative change is possible. Reaching net zero will require applying the very best new building efficiency technologies to the upgrade of existing buildings and the integrated design of new buildings. New policies, rising energy costs, and market drivers such as new energy management technologies will drive this transformation. Policymakers, market actors and other stakeholders will need to combine and focus their efforts to create sound regulatory frameworks, while addressing any persistent barriers that may block progress towardan energy- and carbon-neutral built environment.

The net zero analysis points to additional research questions. Among them:

- How will renewable policy and the investments in renewable energy at a national and local level connect to the net zero building?
- How will vehicle fleet electrification interact with net zero energy buildings?
- What are policy definitions of net and near zero buildings, and how will those definitions evolve?
- How will different climate zones and types measure progress towards this meta-goal of net zero buildings?
- How can compelling events in an existing building's life enable a transition to a net zero building?

To implement the vision of net zero buildings, these and many other questions will need to be answered.

The Institute for Building Efficiency is an initiative of Johnson Controls providing information and analysis of technologies, policies, and practices for efficient, high performance buildings and smart energy systems around the world. The Institute leverages the company's 125 years of global experience providing energy efficient solutions for buildings to support and complement the efforts of nonprofit organizations and industry associations. The Institute focuses on practical solutions that are innovative, cost-effective and scalable.

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