Zero Energy Commercial Buildings Consortium: Building Envelope Working Group *Draft Report*
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Vision for NZECB Envelope Systems

We envision that the building envelope systems used in a society with pervasive NZECBs will provide superior performance and a wider range of performance than typical commercial buildings today. Although significant changes will occur in building envelope components, larger changes are envisioned at the systems level. The intended audience and beneficiaries of this report is the commercial building industry stakeholders, and any findings and recommendations are aimed for their benefit and use. In instances where a recommendation has an unspecified audience or actor, the audience or actor is intended to refer to industry partners and stakeholders.

Key aspects of our NZECB envelope systems include cost-effective versions of the following:

Building Envelope Components

Floors

- In-floor radiant heating and cooling systems common (much less use of drop ceilings)

Roofs

- Cool roofs, including dynamic roof surface properties (variable reflectance and/or emissivity)

Walls

- Whole-wall Insulation systems with high thermal resistance per unit thickness (e.g., R≥10/inch; particularly important for retrofit NZECB in cooler climates)
    - Thermal mass enhancement, using phase-change materials (PCMs) in most effective ways for building type and local climate
    - Integrated curtainwall framing systems – integrate electric and data services, potentially ventilation, etc.

Windows

- Dynamic exterior shading and/or insulation for windows
- Very high-performance windows (whole-window U≤ 0.)

Building Systems Integration

Solar Energy Production

- Roof- and façade-integrated photovoltaic and solar thermal energy production
    - Window-integrated PV

Lighting (e.g., daylighting) and HVAC

- Dynamic, automated windows (variable VT, SHGC) and dynamic, automated exterior and interior shading systems

- Both integrated with HVAC, lighting, and electric demand management controls, as well as occupant preferences and needs

HVAC

- Moveable exterior window shades
    - Integrate with lighting and HVAC systems
- Building thermal mass for shifting space conditioning loads

Ventilation

- Operable windows
- Thorough air sealing, approaching negligible infiltration

Other

- Sensing, diagnostic, and prognostic functionality integrated into much greater range of envelope products.

Crucially, commercial building design and delivery processes will also change significantly to facilitate delivery of high-performance and cost-effective envelope systems for NZECBs.

Design Process

- Comprehensive Building Information Modeling (BIM)-integrated simulation tools seamlessly integrates evaluates energy simulation, system cost, hygrothermal performance, and indoor environmental quality, and environmental performance evaluation throughout the building development process
    - Tools very easy to use, used on most projects
- Performance-based building codes with energy intensity requirements (i.e., kWh/ft^2) instead of prescriptive codes; prior simulation tool a key enabling technology
- Integrated design process standard – cross- functional teams enabling innovative holistic designs.
- Use site-specific concepts the rule, not the exception (e.g., optimal building and design orientation to manage/use solar thermal heat gains, provide daylight).
- Readily available packaged design solutions for typical building types (including modules and footprints)

Delivery

- Comprehensive commissioning of new buildings' envelopes
- Use of pre-fabricated components pervasive to minimize on-site construction issues
- Modular envelopes constructed of components that allow for easy retrofit for future change of building use, users, or expansion
- Delivery of highly integrated solutions drives extensive collaboration among trades and the rise of contractor organizations with cross-trade functionality
- Increased training and competence needed for contractors to install, tune and commission more complex, integrated building systems.

Operations

- Ongoing commissioning for existing building envelopes pervasive

- Typical building operations and maintenance will have become more sophisticated to deal with more complex and integrated systems
- Adaptive (self-teaching and –learning) integrated whole-building control algorithms (e.g., based on neural networks) to dynamically optimize building envelope performance

Retrofit–Specific Vision
In general, the team expects that retrofit NZECBs will have many similar features as new buildings. They do present special challenges, which have different and/or additional requirements.

- Phased and rapid envelope renovation strategies / systems that minimally disrupt building operations; rapid exterior renovations preferred
- Rapid retrofit option screening tools to quickly evaluate energy savings retrofit opportunities for building envelopes
- Effective and aesthetically acceptable high-performance insulation retrofit systems for brick buildings

Solutions

The team developed numerous recommendations for both technology- and process-focused developments to achieve the vision of pervasive NZECBs in the future. These are presented in separate subsections.

Technology Needs

Realizing the vision of widespread deployment of cost-effective NZECBs will require extensive research, development, demonstration, and deployment of a wide range of building technologies. Many of the technologies described in the NZECB vision exist in some form today, but are too costly and/or lack sufficient track record for design and delivery professionals and building owners to implement. Cost reduction is an essential focus of many research efforts, as is demonstrating and improving reliability.

Specific needs for different envelope components and envelope systems follow.

Walls and Roofs

Improving the thermal performance of opaque walls and roofs can be achieved by reducing the thermal bridging due to framing members and/or increasing the R-value of the continuous insulation (ci). Traditional framing materials such as wood, steel or masonry construction have higher thermal conductivities than insulation and act as thermal bridges. Increasing the thickness of the exterior ci beyond typical thicknesses creates new problems for some claddings. Attachment techniques for thicker ci is an emerging technology, has numerous challenges and lack standards. Installation of windows in thicker ci wall systems is also an issue from a structural and thermal perspective. Installing the ci on the interior reduces the leasable floor space so there is no preferred solution.

Insulation systems with high thermal resistance per unit thickness can minimize these problems for both interior and exterior insulation systems, but are still costly and can have attachment / installation and potential long-term durability challenges.

Phase-change materials (PCM) integrated into building envelop materials have the *potential* to reduce heating and cooling energy use. To date, however, they have not been proven to cost-effectively reduce energy use and their application/specification is not understood by the majority of the building industry. Moreover, there are no validated and easy-to use energy modeling programs to evaluate, design, and select building envelope materials incorporating PCMs. The community needs validated software tools to evaluate, design, and select building envelope materials incorporating PCMs. Support should be provided to determine the potential for PCMs to reduce energy use in commercial buildings.

Recommendations

- Develop insulation materials with high thermal resistance per unit thickness (e.g., R≥10/inch) with competitive cost effectiveness for mainstream building applications).
- Develop, test, and validate software to allow designers (architects and engineers) to evaluate, design and select building envelope materials incorporating PCMs. Ensure effective integration with insulation materials.
- Develop and disseminate best-in-class design and construction details, economic (i.e., cost-benefit) analyses, and rigorous demonstration projects for all of these technologies to demonstrate their viability to architects, engineers, and building owners.
- Complete demonstration projects that showcase the commercial viability of the best technologies.

Windows

To achieve the vision of net-zero energy buildings, windows must undergo significant innovation in three different areas: 1) Fixed glazing; 2) Dynamic glazing, and 3) Window system integration.

Fixed Glazing

Window and glazing manufacturer R&D is needed to simultaneously achieve much higher quality, performance, and lower cost. Dramatic increases in the insulating performance of typical windows, e.g., to insulating values as high as R-10 for the entire window system, will be important, particularly for buildings in colder climates and buildings with a window-wall ratio. Triple-pane units provide additional insulating value over dual-pane units. Durability is, however, a concern for multiple pane units. In particular, as the number of air gaps increases, so does the stress on the seals. Also, with multiple panes have multiple seals. Both factors increase the risk of premature seal failure and/or greater rate of gas loss.

In existing buildings, in order to increase thermal performance in the glazing, triple pane may be required, but existing frames often cannot accommodate the increased glass thickness and would need to be replaced too, increasing cost. Consequently, windows that achieve high performance within a limited thickness have particular value for renovation of existing buildings.

Recommendations:

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

Dynamic Glazing

Dynamic glass, i.e., glass with variable visible transmittance (VT), can enable close to real-time optimization of solar heat gains and glare management through windows. A limited number of products with dynamics glass is currently available on the market, but their current cost prevents widespread use.

Recommendations:

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

System Integration

Envelope system integration includes integration of window, wall, and roof system design and control with that of other envelope in building systems, mainly mechanical moveable shading products (exterior louvers, double-skin curtain walls with integrated automated blinds etc.), external fixed shading, interior lighting systems, and HVAC systems. Implemented and controlled properly and maintained, together these systems can dynamically optimize solar heat gains to reduce lighting and HVAC energy consumption while also effectively managing solar glare. In practice, today such integration is challenging from several perspectives.

More sophisticated solar shading products have become the standard in European building design, but this is not the case in the U.S. Key barriers to greater use of such shading appear to include cost effectiveness, real or perceived reliability concerns, and aesthetic concerns. Indeed, *static* exterior shading has only just become popular in the U.S. and, in many cases, the exterior shades do not extend far enough to be functional and act mainly as a design accent.

Beyond the devices themselves, dynamic solar control (either through mechanical shading or dynamic glazing) and highly insulating window and glazing systems need to be positioned appropriately on the envelope to provide effective daylighting design and integrated with HVAC and dimmable lighting controls to provide maximum energy benefit. Crucially, these systems require a holistic design and operations approach to maximize whole-building energy performance and occupant comfort (i.e., access to views and freedom from glare). This requires integration of envelope, interior, lighting and daylighting, and HVAC design at the same point in the design process. Good education throughout the design community on how to use and position windows for greatest effect is necessary.

Recommendations:

- Review and evaluation of building envelope practices in Europe to understand why dynamic solar control has become a standard part of building design. Develop a roadmap/plan to accelerate the adoption of such products, including (as necessary) development of systems that are cost effective for widespread application in commercial buildings

- Develop standardized control packages and solutions to effectively operate these high-performance complex systems, are needed; this could come from greater use of centralized monitoring and control (including remote operations)
    - Simplified access to building integration modeling (BIM) data to enable this
- Develop and institutionalize holistic design methodologies through universities and organizations such as AIA.

Building-Integrated Photovoltaics (BIPV)

Building-integrated photovoltaics (BIPV) integration into new and existing building envelope systems will be an important element in achieving widespread NZECBs, most notably for buildings that cannot meet their energy needs from the available roof area (due to either building height or high energy demand). At present, however, BIPV products are not widely available and not cost effective in most building applications. Moreover, when integrated into walls or windows, they usually produce significantly less electricity/year than conventional PV panels. In addition, BIPV tend to have lower reflectances than most building materials, which increases surface temperatures. In turn, this increases building air-conditioning loads and decreases PV output, and may also have the potential to adversely impact roof durability.

Recommendations:

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

Building Envelope Commissioning

Evidence suggests that high-performance building envelope systems are more sensitive to improper installation than conventional systems. For example, water is less likely to accumulate over time in a poorly insulated wall system than a high-performance wall due to the larger thermal energy flows through the poorly insulated wall system. Furthermore, more favorable building envelope economics depend on cost savings achieved from down-sizing mechanical systems due to lower envelope loads. If the envelope is not constructed properly, it results in either an HVAC system that cannot meet the higher-than-designed space conditioning loads or diminishes the degree of down-sizing (and cost savings) that engineers are willing to specify.

Consequently, this puts a premium on ensuring that high-performance wall systems are properly installed. Unfortunately, problems with existing building enclosures are not usually detected until they have reached a point where the symptoms become apparent to building occupants (e.g., visible mold growth, bad odors, visible water damage or stains, etc.). Regular, thorough inspections would help to diagnose problems before they become significant, but these are labor-intensive and, hence, very costly. In addition, there is a dearth of feedback on the *real* world performance of post-construction envelope performance measurements that would enable architects and engineers to improve the design and implementation of future envelope systems. Consequently, we recommend developing ongoing commissioning techniques for building envelopes. Key issues to address include: air barrier performance; R-value; water infiltration. Ideally, these techniques would provide both diagnostic (assessment of current state and identification of the root causes of problems) and prognostics (prediction of the future evolution of the envelope's condition, to enable maintenance optimization). Similarly, it would be desirable to develop a similar technology to enable rapid evaluation of the installation quality of envelope systems installed in new buildings.

Recommendations:

- Develop easy-to-use technologies to enable high-speed evaluation of envelope integrity/condition; semi-automated techniques are likely essential to make this cost effective (dramatically reduce the labor intensity required).
- Evaluate the potential for *in situ* sensors that could enable or facilitate commissioning of new or existing building envelopes
- BIM could be a valuable enabling technology to facilitate ongoing commissioning of building envelope by making it easier to find and access information required for ongoing commissioning
- Carry out rigorous demonstration projects to show the cost effectiveness of commissioning systems.
- Use data developed from envelope commissioning to clearly identify where (and, ideally, why) the most common and severe shortfalls in building envelope system design and construction; ensure feedback of these findings to design and construction professionals to avoid future problems.

Project Design & Delivery

Effective integration between different building systems lies at the heart of designing and constructing the most energy-efficient and cost-effective NZECBs achievable. Unfortunately, the most prevalent design and construction processes currently used are barriers to achieving the vision of widespread NZECB.

It is clear that a more holistic approach is needed, i.e., widespread use of an integrated project design and delivery lies at the heart of realizing this vision. Design and Construction practices need more cooperation and collaboration.

The construction administration and delivery processes suffer from several shortfalls that make construction of a NZECB very challenging. Key challenges include:

- Building trades don't easily work/collaborate together to get building envelope interfaces, such as integrated air barriers, correct ("not in my scope" issue).
- The common practice of value engineering (VE) usually clashes with any energy efficiency objective, as it is focuses on minimizing first cost instead of life-cycle cost. As such, it often removes the "value" out of the project.
- Challenges identifying a single entity with responsibility for envelope quality/performance.

As noted earlier, correct design and implementation of building envelopes is essential to the delivery of envelope systems with superior energy performance and durability. In practice, this is not often achieved due to a lack of knowledge and understanding of building science and high-performance building envelope design, leading to insufficient or inaccurate design details and resulting improper system installation. For example, fenestration integration is very challenging to effectively implement in many types of wall cladding in practice. Unsuccessful integration can enable the infiltration of water into the wall system, potentially damaging the structure, creating indoor environmental quality issues, and reducing the wall system's thermal efficiency.

Recommendations:

- Support the use and development of Integrated/High performing/High Collaborative Design and Construction Team.
    - Help develop effective certification for the required expertise (LEED accreditation is *not* sufficient enough to understand the complications of building science issues). ASHRAE has implemented a High Performance Building Certification; this is more specific to HVAC, and could be expanded to include building envelope-related issues.
- Develop codified standards for Integrated Project Delivery (IPD) as an alternative contractual model. Aspects of the IPD approach may enhance the ZEB envelope delivery, while information sharing from design and construction phase IPD information may support the O&M phase.
- Develop templates for strong specifications of building envelope components and systems commonly used in NZECBs to address obstacles such as substitutions.[1]
- Develop and disseminate best-in-class design and construction details, economic (i.e., cost-benefit) analyses, and rigorous demonstration projects for all of these technologies to demonstrate their viability to architects, engineers, and building owners.
    - Complete demonstration projects that showcase the commercial viability of the best construction practices.
    - Train construction workers how to properly implement key envelope details. The unskilled labor market is a critical component and needs to be addressed as well.
- Develop training materials (courses on best practices and processes, case studies, etc.) for design and delivery professionals, including sub-contractors, to help facilitate greater and more effective use of IPD. This training should include team-level, i.e., process-focused training.

Risk Reduction

In general, the U.S. construction market is very conservative and slow to adopt new technologies. In most cases, NZECBs lie well outside the "comfort zone" of building owners, designers, and construction professionals. At present, the Design and Construction team (including construction manager, main subs, and estimators) are rarely committed to ZEB upfront, as a learning curve exists for the industry. This creates a high degree of uncertainty for all parties, increasing the real and perceived financial and liability risk of pursuing NZECBs. Key issues include:

- Inexperience designing and delivering NZECBs increases the financial risk these professionals face (both to deliver the project and legal exposure), leading to increased design and delivery costs.

[1] This does not, however, obviate the need for diligence by the design/construction administration team at bid and during construction administration.

- Limited real-world cost, energy performance, reliability, and maintenance data for more advanced building technologies and systems needed for NZECBs. This makes estimating and building budgeting very challenging, leading to conservative (i.e., high) cost estimates.
- Perception of design professionals' liability when performance goals are not attained.
- The current pool of experienced consultants is very limited.[2] Since design and construction of effective NZECBs depends heavily on a strong understand science, repercussions of bad buildings (and potential liability) may hinder achieving NZECBs at a large scale.

Recommendations:

- As noted earlier, develop and disseminate rigorous economic (i.e., cost-benefit) and post-occupancy savings (estimated vs. real) and analyses for NZECBs and core technologies for NZECBs based on actual projects to demonstrate their viability to building owners, architects, and engineers. The projects included in these analyses should come from a range of climate zones, building types, and new and retrofit projects.
- Carry out rigorous studies to assess how savings on operations may affect the building value and re-sale value, with the presentation of these studies targeted and accessible to support commercial owners and design teams in the upfront decision process.
- Carry out rigorous studies to evaluate the potential for productivity gains and reduce employee health and absenteeism costs from enhanced indoor environments enabled by high-performance building envelope systems. Although very challenging to definitively evaluate, a positive finding could have a dramatic impact upon the adoption of high-performance building technologies that enhance the indoor environment, including potentially many building envelope technologies, since employee salaries are approximately two orders of magnitude greater than energy costs in an office building.
- Develop high-performance and cost-effective building envelope commissioning technologies (see "Building Envelope Commissioning" above, in the "Technology Needs" section).
- Work with industry and association partners to significantly increase educational programs designed to build the awareness and expertise of building envelope practices and processes needed to design and construct ZEBs. Target audiences for this include all leading standard-and code-setting groups including ASHRAE, ANSI, ASTM and ICC. Associations include the AIA, USGBC, NAHB, IFMA, BOMA and likely others. This training should also address Owner's Project Representatives (OPR's), who play a very important part in directing project goals and objectives.
    - The training could be recognized under professional certifications/continuing education programs.
- Implement a coordinated approach by the design and construction team using a quality control process such as building envelope commissioning, as described in NIBS Guideline 3-2006, *Exterior Enclosure Technical Requirements for the Commissioning Process*, and ASHRAE Guidline 0-2005, *The Commissioning Process*. This "technology" is just beginning to be used and we need to push it forward more quickly.

[2] Green washing is a large issue that needs to be addressed. As seen with LEED, there are a lot of entities and products in the AEC community that claim they have expertise and are "green".

  - Large public organizations could take the lead on implementing building envelope commissioning on their projects.
  - Document and publish the cost and benefits of the process to show how the process works, and show where it does not work.

Building Codes and Standards

Building codes can contribute to or impede the construction of NZECBs several different ways. Commercial building energy codes, such as ASHRAE 90.1, typically have prescriptive minimum performance standards for discrete envelope (and other) components. This philosophy of viewing building components as discrete, separate elements runs contrary to the integrated design process (IDP) envisioned for ZNECBs that emphasizes system- and whole building-level savings. For example, building energy codes may call for a reduction in window-to-wall ratio, but this may not be optimal for buildings with integrated building enclosure systems (e.g., with dynamic shading devices) in some climates.

Local building code officials play a key – and often limiting – role in the construction of high-performance buildings. Among the vast number (i.e., tens of thousands) of different building code jurisdictions in the U.S., the capability to effectively evaluate novel energy-saving building envelope technologies that enable NZECBs varies dramatically. In jurisdictions that lack this knowledge and resources, this can dramatically limit the building envelope technologies that can be deployed and, in turn, the ability to cost effectively realize NZECBs. This challenge likely becomes more acute for aspects related to system integration. In addition, historic commissions can strongly influence the scope of envelope retrofits for existing buildings. Requirements to maintain a desired character for the exterior of buildings in some locations, e.g., brick facades, can eliminate the possibility of high-performance external insulation solutions and limit the type and increase the cost of re-fenestration options significantly. Finally, a lack of energy code adoption and effective enforcement reduces the likelihood that NZECBs will be built even if required.

Recommendations:

- Advocate for standards and codes organizations to more widely use "reach" codes, such as the International Green Construction Code and ASHRAE 189.1, that give building owners, architects and others a clearer sense of the direction and level of required building performance.
- Move away from current prescriptive building energy codes to *performance-based* codes. This goes hand-in-hand with comprehensive use of a whole-building systems perspective as the norm instead of the exception.
- Create standard guidance for local building code officials to consider and evaluate the use of envelope technologies key to achieving NZECBs.
- Develop and support forums/consortia for providers of ZEB-supportive technologies (including systems integration) to meet with standards and codes organizations to increase knowledge of these technologies. Use this process to seed discourse so that the standard- and code-setting process considers and integrates technologies at a faster pace. Removing the current boundaries between groups developing envelope and lighting codes for example will be critical.

- Develop design packages for cost-effective energy-efficient renovation of historic building envelopes. For example, ASHRAE 90.1-2010 will provide verbiage for interpretation of dynamic fenestration and this is a good step forward.

Design and Construction-centric Whole Building Energy Modeling

The use of whole-building energy models to make effective tradeoffs between envelope, lighting, and mechanical systems is integral to realizing the greatest energy savings at most reasonable cost. Unfortunately, the complexity and cost of applying these models significantly limits or prevents their use in most projects. Currently, energy, moisture, cost, and environmental factors are not incorporated in an integrated modeling tool, requiring designers to evaluate multiple factors with multiple tools.

Recommendations:

- Develop a user-friendly (and free) front-end interface existing whole-building performance modeling system (including daylighting and dynamic glazing features) integrated with BIM software so that use of this system increases substantially among architects, building owners, and technology providers.
- The analytical tools needed to assess the whole-building energy performance and cost (i.e., based on building component and system sizing) of potential technologies used to achieve NZECBs goals must keep pace with the available emerging technologies. Even the most recent releases of building modeling software available to the general public (e.g., EnergyPlus) fall short in their ability to model some advanced integrated systems of building components. This is especially so for emerging technologies or combinations of such technologies that might accelerate NZECB deployment.[3]
- Develop and maintain comprehensive life cycle cost analysis design tools to support decision process and delivery. These tools should include: energy performance; material and installed costs; maintenance costs; and current utility costs and cost escalation. For example, a transparent and flexible (regional) web-based tool may be beneficial.

Retrofit-Specific Challenges

Cost and time will be the largest hurdles for major envelope renovation projects. It is typically much more expensive to design in high-performance envelope solutions here than it is in new buildings. Unknown conditions are often a significant barrier, with significant cost and schedule implications. Physical constraints on renovation scope can limit energy savings potential. For example, the overall building geometry and orientation are typically set and, in many cases, the building envelope will be largely retained. In some cases (as described in the "codes" section), historic preservation requirements can severely limit the range of building envelope solutions that can be implemented.

[3] Proprietary models possessed by consultancies with expertise with modeling and these technologies may be able to develop whole-building energy models based on this combination of technologies, but others more widely and cost-effectively available to the general public do not.