ASHRAE 2020:

Producing Net Zero Energy Buildings

Providing tools by 2020 that enable the building community to produce market viable NZEBs by 2030.

A Report from

American Society of Heating, Refrigerating and Air-Conditioning Engineers

Prepared by
ASHRAE Vision 2020 Committee

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Foreword

To create and recreate the world's building stock in a manner that sustains the well being of humanity requires planning, concerted effort, and bold action. Formed by our imagination, a single vision must be shared by all who design, build, and operate the structures that house life on our planet and that foster the productivity that defines our civilizations.

This report describes the vision held by members of the American Society of Heating, Refrigerating and Air-Conditioning Engineers. This vision is of the year 2030 when buildings will produce as much energy as they use.

We believe this vision can be realized only if ASHRAE, working within the framework of the building community, provides to its members by the year 2020 the tools necessary to design, construct, and operate what we call *net zero energy buildings* (NZEBs). Our thinking and our vision must now be clear to attain this critical milestone.

ASHRAE Vision 2020 Ad Hoc Committee

ASHRAE 2020
Vision, Position, Strategies, Actions

ASHRAE's Vision to Achieve NZEBs

ASHRAE's vision for net zero building technology is that the building community will produce market viable NZEBs by the year 2030.

ASHRAE's Position on NZEBs

ASHRAE will drive NZEB technology by getting the needed tools into the hands its membership by 2020 to ensure its NZEB vision is realized.

ASHRAE's NZEB Strategies

• Research activities, educational products, and publications need to be developed by the ASHRAE Technology Council and the ASHRAE Publishing and Education Council. A listing with target dates for completion must be presented by each council.

• Strategies must be coordinated among councils, technical committees, and standing committees.

• A Green Team Resource Group will be an important component of a public relations and marketing campaign that has two objectives: to energize the ASHRAE membership and to communicate to the global community of facility design, ownership, and regulation the basis for achieving net zero energy usage in facilities.

• Resource guides and presentations must be produced to take the benefits of net zero energy usage to the general public.

• Current and future ASHRAE energy-related products must not be allowed to become obsolete by the development of any products required to produce net zero energy usage in facilities. All ASHRAE publications and educational products must move in unison to reflect net zero energy usage.

ASHRAE's Actions to Achieve NZEBs
(As recommended by the ASHRAE Vision 2020 Committee)

- An NZEB will be defined as a building that produces as much energy as it uses when measured at the site.

- New buildings will be the focus of NZEBs, but existing buildings must be included.

- ASHRAE will develop a rating system and branding for buildings, considering design and operations.

- ASHRAE's rating system and rating will apply to both new and existing buildings.

- The schedule approved by the ASHRAE Board of Directors in approaching NZEBs will be followed.

- Memorandums of Understanding will be recognized among AIA, IESNA, USGBC, and ASHRAE on NZEBs, with support from EPA and DOE.

- ASHRAE's Associate Societies Alliance will examine the impact of NZEBs in light of the global sustainability movement and ASHRAE's global strategies.

- ASHRAE will identify key players within the larger context of the building environment community—such as computer equipment manufacturers— and will engage them in solutions to reduce standby loss and parasitic power use (plug loads and power transformers). A presidential level committee may be required.

- ASHRAE will host a leadership roundtable of owner/manager groups (such as BOMA, IFMA, HEC, ICS, CORENET, Heinz, Intl. Asset Management Council, REIT, and international organizations) to explore integrated design possibilities to reach NZEBs.

- ASHRAE will swiftly address the highest priority research items working through the Research Advisory Panel and the USGBC Research Committee.

- The *ASHRAE Handbook* series will be revised to include content on how to achieve NZEBs.

- ASHRAE standards and special publications will be reviewed to identify those with impact on energy.

- Unregulated loads will be added to Standard 90.1, perhaps establishing a recommended level of W/ft^2.

- Target energy budgets by climate zones and building types in Standard 90.1 will be created.

- The *Advanced Energy Design Guides* (AEDGs) are the best path for NZEBs. They provide design guidance outside the standards process, therefore providing the “above code guidance” that is essential.

- The AEDG Steering Committee will produce NZEB guides in place of the 70% guides planned for 2015.

- The AEDGs will be expanded by providing alternative packages for reaching 30% in existing AEDGs guides by 2008.

- ASHRAE will add emphasis to user-friendly energy modeling tools and interfaces included in *ASHRAE’s Research Strategic Plan*.

- E-Learning modules will be developed to include NZEB content.

- A Certified Sustainability Design Expert program will be launched, including material on NZEBs.

Net Zero Energy Building Technology

Buildings consume 40% of the primary energy and 71% of the electrical energy in the US. Energy use in the US commercial sector is expected to grow by 1.6% per year, driven by economic expansion and population growth that require more and more facility space each year. This is resulting in an energy impact that is increasing faster than all of the energy conservation measures being taken and retrofits being made to buildings.

The concept of NZEBs looks at just the energy flows of the building, not the overall sustainability of the building. It is a step, a critical one, toward achieving the objectives of building sustainability as articulated in *ASHRAE's Sustainability Roadmap*.

Defining NZEBs

The vision of a NZEB is to as much energy collect from renewable sources as the building uses on an annual basis while maintaining an acceptable level of service and functionality. Buildings can exchange energy with the power grid as long as the net energy balance is zero on an annual basis.

The intent of NZEBs can be defined using several metrics. Torcellini et al. used four: site energy, source energy, emissions, and energy cost. Each of these metrics has pros and cons, and each addresses different aspects of net zero energy buildings.

Net Zero Site Energy Building

A net zero site energy building produces as much energy as it uses when measured at the site.

This definition as a goal is very useful, as it can be verified through on-site metering. It tends to encourage energy-efficient designs; however, it does not distinguish between fuel types or account for inefficiencies in the utility grid. The site must also be defined. Is the site just the building footprint, or does it include the entire property? What happens if you cover a parking lot with photovoltaic panels to achieve your zero energy building, only to develop that space later into a new building? This would give higher priority to photovoltaic systems that are within the building footprint because it is always part of the building.

Net Zero Source Energy Building

A net zero source energy building produces as much energy as it uses compared to the energy content at the energy source on an annual basis.

The system boundary is drawn around the building, the transmission system, the power plant, and the energy required getting the fuel source to the power plant. This tends to be a better representation of the total energy impact compared to a site definition. It is challenged, however, by difficulties in acquiring site-to-source conversions and by the limitations of these conversions. Fixed conversion factors exist today, but do not account for dispatch of energy with time of day and the changes in dispatch as new buildings and the new power plants to supply them come on-line.

This definition can depend more on how the utility is buying or producing the power rather than on the energy performance of the building. So if someone wants to construct a building in an area with a large percentage of hydroelectric energy, it may have a low source energy impact; however, putting the building in that location may necessitate new fossil fuel generation plants and the building may actually use the new generation capacity, which is coal. Therefore, this analysis is very difficult to conduct and is dependent on assumptions of future energy sources.

Net Zero Energy Cost Building

Building owners are typically most interested in net zero energy cost buildings, and tend to use energy efficiency and renewable energy as part of their business plan.

This definition, like the site NZEB definition, is easy to verify with the utility bills. Market forces provide a good balance between fuel types based on fuel availability. Costs also tend to include the impact of the infrastructure.

Getting to zero may be very difficult or impossible because of utility rate structures. Many rate structures will give credit for energy returned to the grid but will not allow this number to go below zero on an annual basis. As a result, there is no way to recover costs incurred by fixed and demand charges.

Finally, imagine a day when all buildings approach zero energy. Utility rates will need to be changed to maintain a reliable utility grid.

Net Zero Energy Emissions Building

The fourth definition, a zero energy emissions building, looks at the emissions that were produced by the energy needs of the building.

This is probably a better model for "green" energy sources; however, like the source ZEB definition, it can be difficult to calculate.

A Single Definition for NZEB

Based on today's building stock, each metric represents a positive direction toward achieving buildings that lessen their environmental impact and conserve nonrenewable resources.

There is still a need to create a single definition, however. Without this, there is a vacuum that leaves questions as to if a building can be universally considered as being an NZEB.

Ultimately, the only way to measure if a building is an NZEB is to look at the energy crossing the boundary. Other definitions, including source, emissions, and cost are based on this measured information and include weighing factors and algorithms to get to the metric of interest.

Because of the complications involved in making these computations, site energy measurements have been chosen through an agreement of understanding between ASHRAE, the American Institute of Architects (AIA), the U.S. Green Building Council (USGBC), and the Illuminating Engineering Society of North America (IESNA).

Implications for Industry

While most of the responsibility of achieving NZEBs will fall on the shoulders of designers, there are considerable and important challenges for all sectors of the building community.

If NZEBs are to become reality, manufacturers and designers must be better able to integrate systems into buildings that may be significantly different from most buildings constructed today. Designers will need the tools to design and apply better integrated equipment, manufacturers will need to produce ultra-high-efficiency equipment and know how to best apply it to buildings, and both will have to be able to better monitor occupants' needs and provide comfortable conditions, taking advantage of everything that nature has to offer, including human ingenuity.

The following are some of the tools and technology changes that will impact the industry.

Higher Efficiency Systems and Equipment

Certainly, there will be a need for ultra-high-efficiency systems, including more variable speed and integrated systems. High-efficiency systems are systems that minimize energy use throughout the seasons and for varying cooling loads imposed by the building's users and the outdoor ambient.

Equipment will have to be fully integrated so that waste energy and other "free" energy sources are used to their maximum extent. This is very different from the current practice, where discrete equipment performs independent, discrete tasks. Natural and mechanical ventilation will have to be optimally integrated where appropriate.

Manufacturers will have to make available smaller capacity equipment with better part-load profiles.

Better dehumidification and moisture control will be required that allows cooling to be separated from dehumidification. This could allow the saturated evaporator temperatures to be higher and, thus, have a higher COP. Equipment design rating points and designs may need to change.

Fundamentally, manufacturers will need to understand the potential market for NZEBs so they can design systems to meet that market. Planning decisions need to be made many years in advance of commercialization.

Design Tools

Architects, engineers, and manufacturing companies will need refined tools for properly sizing and selecting HVAC equipment in NZEBs. Also needed are tools to better integrate building form and fabric as part of the heating, cooling, and lighting system—as well as balancing the remaining load with the HVAC and electric lighting systems—all to satisfy the occupants' needs.

Tools will be needed to improve design of daylighting and hybrid ventilation, integrating low-energy solutions with traditional and next-generation equipment.

Also, tools will be needed for comparing applications of different types of equipment and system arrangements to allow engineers and owners to select the most energy-effective approach for a given building.

Clear explanations of the advantages of various types of systems for particular building applications are needed to help designers and owners make educated choices.

Building simulation tools need to be refined for easier and less costly use, permitting low budget projects to take advantage of their capability. In addition, common building types should be "presimulated” such that common solutions can be readily accepted by industry.

Energy Storage

Metrics and methods need to be developed to better use the energy resources available, both on site and off site. This would involve identifying methods of using energy storage. Many metrics used today show storage as a negative to the building, but it is known to better use energy resources.

Enhanced Building Automation Systems and Controls

Sensors are needed that are inexpensive and reliable for wide distribution in buildings to achieve better comfort control with less energy use. It is desirable to have these sensors perform multiple functions, such as sensing temperature, humidity, and carbon dioxide concentration. The cost of installing sensors and programming them is a barrier to wide-scale adoption; advanced sensor technology should be more plug/play, and technologies, such as wireless, may help in reducing the cost.

Better sensors are needed to detect when natural ventilation is being used and when daylighting is available. Accurate occupancy sensors would all benefit energy impacts of buildings. Smart systems are needed that do not condition spaces that are not occupied and can sense/predict when a space will be occupied, and avoid condensation during unoccupied periods.

Energy can be saved over time by self-commissioning systems that continuously monitor their performance against design intent and re-tune as needed.

Indoor Air Quality

Tighter building envelopes and more carefully designed and installed ventilation systems will allow for better control of indoor air quality. Source control through selection of low-emitting materials and furnishings, along with advanced air filtration and treatment technologies, will reduce requirements for outdoor air ventilation. As a result, energy consumption of heating and cooling ventilation air will also be reduced.

Performance Standards

Standards for measuring the performance of integrated systems within the building will be needed.

Achieving NZEBs: Actions by ASHRAE

On December 1, 2007, ASHRAE President Terry Townsend drew from the building design, research, owning, and supplier communities to appoint an ad hoc committee with the following charge:

> **Develop guidance and strategy which would enable by 2020 the development of energy-related products, research in renewable energy systems, and the sequencing of the various identified activities that will produce net zero energy usage for all types of facilities by 2030.**

The membership of the committee was as follows:

Ronald E. Jarnagin, Chair, Pacific Northwest National Laboratory
Thomas E. Watson, P.E., Vice Chair, McQuay International
Lee W. Burgett, P.E., The Trane Company
Dale E. Carter, Dec Design Mechanical Consultants Ltd
Dr. Donald G. Colliver, P.E., University of Kentucky
Hugh D. McMillan, III, P.E., Syska Hennessy Group
Mark S. Menzer, Air Conditioning and Refrigeration Institute
John Montgomery, Public Building Commission of Chicago
Victor Olgyay, A.I.A., Rocky Mountain Institute
Dr. Andrew K. Persily, National Institute of Standards and Technology
Thomas H. Phoenix, P.E., Moser Mayer Phoenix Associates PA
Dr. Paul A. Torcellini, National Renewable Energy Laboratory
Dr. Constantinos A. Balaras, P.E., Group Energy Conservation IERSD
Dr. Bruce Hunn, ASHRAE Staff Liaison

ASHRAE's Strategies to Achieve NZEBs

To achieve the vision of "ASHRAE 2020: Producing Net Zero Energy Buildings," the committee recommends the strategies listed below:

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• Strategies must be coordinated among councils, technical committees, and standing committees.

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• Resource guides and presentations must be produced to take the benefits of net zero energy usage to the general public (completion by 2007 Annual Meeting).

• Current and future ASHRAE energy-related products must not be allowed to become obsolete by the development of any products required to produce net zero energy usage in facilities. All ASHRAE publications and educational products must move in unison to reflect net zero energy usage.

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Implications for ASHRAE Members Worldwide

The methods to achieve NZEBs will impact building designers and operators in varying degrees based on climatic conditions, demographic factors, and geographic location.

The worldwide view of being sustainable and energy efficient varies tremendously. For example, many European countries have made significant progress along the sustainability path. As another example, China is aggressively developing building energy standards. At the same time, many developing nations are struggling just to raise their basic standards of living.

ASHRAE's vision to achieve NZEBs is initially focused on North America. If, however, we are to make this an "initiative" for use globally, the ASHRAE membership worldwide will need to assist the Society by identifying the regional construction standards, climatic zone variations, economic viability, and other driving forces in each respective country.

There will be challenges such as the perception of engineers in one nation imposing its standards on another. To address this, a "collaborative team effort" will need to be nurtured to achieve the goal of NZEBs worldwide. Regardless, the intent of this document is to identify the actions by ASHRAE that will provide the tools and guidance to engineers that will lower building energy consumption while reaching achievable sustainability goals.

Role of Those Outside the ASHRAE Community

The ASHRAE community, including the partners involved in developing the principal standards used for the built environment (Standards 90.1, 62.1, 55, et al.), has a strong influence on energy consumption and consequent environmental impacts. However, many other entities play an equally important role. It is important that ASHRAE recognize these entities and engage them in the process of change.

On the energy supply side, private enterprise is becoming heavily involved with renewables (albeit with some government subsidies). Regulated utilities are major factors in generating electrical power. Various governmental bodies (local/state/federal) have influence on the supply side, whether it be with incentives and/or regulations and rate setting. Also, industry is a major factor in the distribution of energy in the deregulated environment. Each of these entities has a role to play in the 2020 vision for NZEB.

Alternative power generation methods and sources will be a major factor in the political arena and in terms of environmental impact. Nuclear power is a hot political topic but has the potential to strongly reduce CO_2 emissions. The Nuclear Regulatory Commission will play a role. Coal will have an important influence for a long time to come despite concerns about emissions. Gas and oil will continue to get the public's attention as the cost continues to move upward. This means a host of organizations must be included in the 2020 vision.

Conservation of Energy

Plug loads, such as computing equipment, have become a significant factor in the total energy picture. Both increased usage and improved technology are likely to influence the future. Organizations, such as IEEE, can provide expertise and understanding of this segment.

Architecture (site, orientation, etc.) plays a role in determining the climatic load imposed on the building. AIA can be instrumental in providing guidance to minimize the impact on energy consumption by improving the form and fabric of the building.

Building rating systems do much to encourage good practice and reduce energy consumption; USGBC et al. use ASHRAE standards as they pursue transforming the marketplace.

Organizations developing model codes set the bar for a host of local jurisdictions across the country; ICC, NFPA, et al. are key disseminators of energy standards.

The HVAC&R industry supplies products that are primary consumers of energy as they provide services to building occupants; ARI represents the industry and participates in the regulation of energy consumption.

Building contractors need to implement and follow through with energy-efficient designs, including training trades people on the proper implementation of technologies.

A variety of governmental organizations are active participants in a conserving role by conducting research, writing standards, and implementing energy conservation in government facilities; DOE, EPA, and GSA are principal groups.

National laboratories should be used to implement national research plans to address major hurdles facing the building industry as it moves toward NZEBs.

Metrics and Recognition

A number of activities/initiatives should be pursued to encourage adoption of NZEB technology and also to support NZEB marketing activities.

The three primary options explored by the committee were building certification, accreditation of professionals, and labels or dashboards that highlight the energy consumption of a given building. Each of these options is discussed below in terms of how they might fit into ASHRAE's NZEB programs, along with specific recommendations for next steps to define and ultimately implement them. Names for the programs are not the focus of this discussion, as such issues would be addressed by marketing efforts associated with NZEB.

Building Certification

Certifying buildings for net zero energy consumption could serve to motivate building owners and designers, thereby providing a potential opportunity for ASHRAE to provide leadership in this issue. This certification could be coordinated with ASHRAE's current Technology Awards programs, recognizing NZEBs and encouraging more.

Some of the reasons to certify buildings include market leadership, credibility, and visibility, which are also the motivations used by ENERGY STAR® to describe the benefits of their programs to architecture firms (http://www.energystar.gov/index.cfm?c=new_bldg_design.new_bldg_design_benefits). Market leadership can establish a building, along with the owner and design team, as a top performer. And having an ASHRAE-certified building would provide the credibility to make such recognition meaningful in the marketplace. Certification and an awards program would provide the visibility that can motivate building owners and designers.

Building certification could take the form of a plaque, label, or certificate that could be display prominently in a building. Many building owners already do this with their ASHRAE Technology Awards. There is a European program in place, called *EP Label* (www.eplabel.org), that describes the overall energy efficiency of a building relative to some benchmark values as shown below.

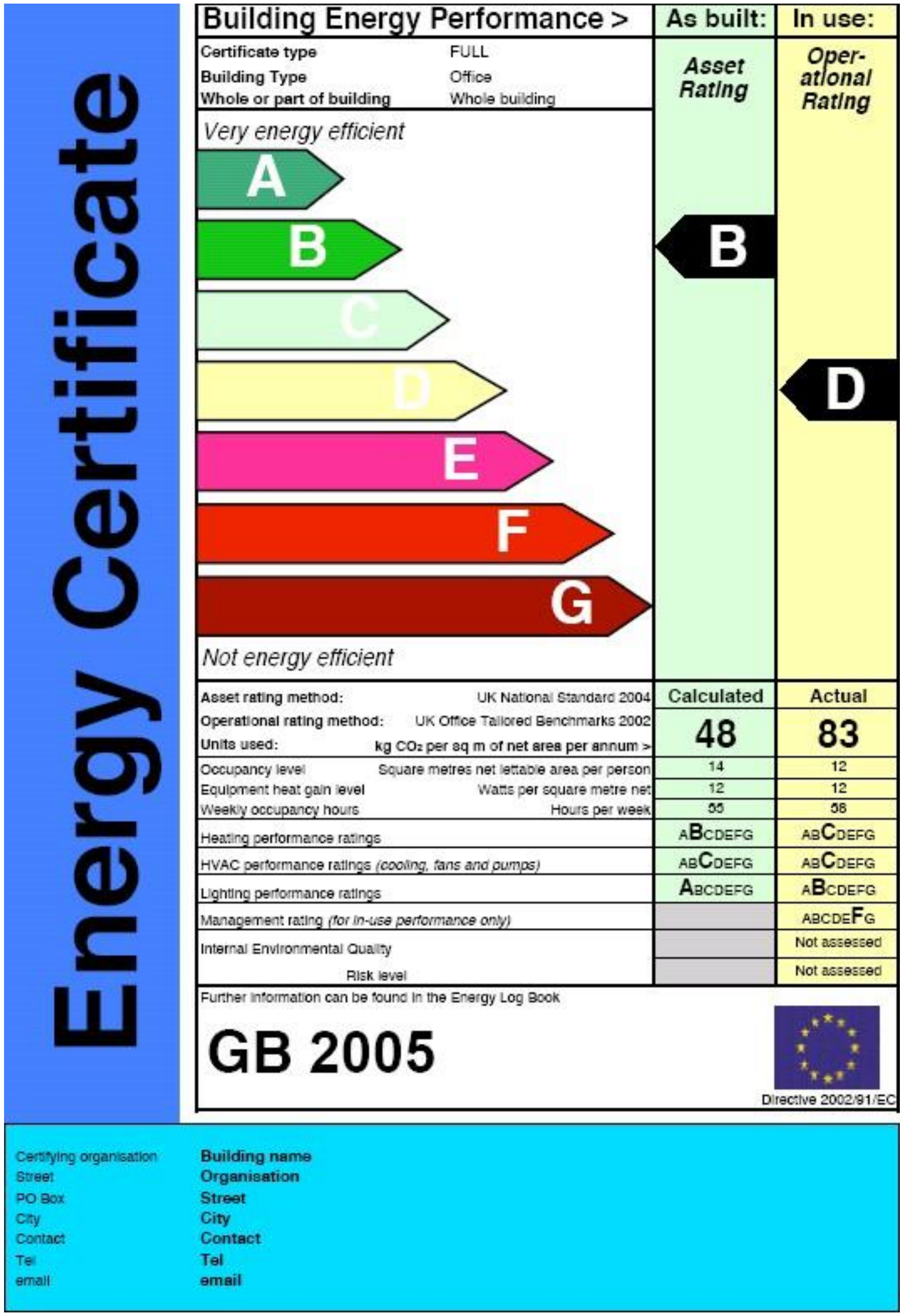


Figure EP Label

Note that the EP label includes an indication of actual energy consumption in addition to the expected value based on design, which is an important indicator to include. Such a static label should be updated periodically, perhaps annually, to reflect performance changes over time. Such updating could be based on utility bills.

Building certification raises the issues of adjudication and the infrastructure necessary to support a rating program. If ASHRAE chooses to not pursue a labeling system on its own, the Society could focus on the required tools and collaborate with another organization on the actual labeling program. ENERGY STAR currently endorses achieving low carbon buildings through AIA's 2030 Challenge, and a similar endorsement could occur via ASHRAE's NZEB program. Other associations in the building community may have interest in partnering with ASHRAE to create a building labeling program. (Perhaps Zero ENERGY STAR could be considered, collaborating with EPA to leverage their infrastructure.)

Accreditation of Professionals

ASHRAE will accredit individuals in the field of NZEB. This will encourage the practiced of NZEB technology; however, ASHRAE must address the issue of adjudication and must provide the necessary infrastructure to support it.

The benefits of ASHRAE's certification programs are clear.

They are developed by industry practitioners who understand the knowledge and experience that are expected for superior building design and system operation. The ASHRAE Learning Institute supports the certification effort, thereby providing a complete learning process. ASHRAE enjoys a worldwide reputation as a leader in providing guidance for HVAC&R design, and the Society's certification programs reinforce that reputation.

To an employer, an ASHRAE certification lets employers know that the certification earner has mastered a body of knowledge in a specific aspect of HVAC&R design, as determined by industry professionals in that field, and has met specified eligibility requirements. This knowledge will serve as the springboard for a certification earner's continued professional development in the building industry.

To a building owner, a firm that employs ASHRAE certification earners has demonstrated a corporate commitment to the professional development of its employees and a dedication to providing the best possible resources for building design projects.

To engineers in the HVAC&R field, an ASHRAE certification broadens their knowledge base. It also allows them to stand out from the crowd and may improve options for employment, promotion, and selection for prized design projects.

To the public, more knowledgeable engineers design HVAC&R systems that are more energy efficient and provide better indoor environments. This impacts current generations and generations to follow. ASHRAE encourages its members and other individuals who pass through its certification program to use the knowledge gained to improve the world around them.

Measuring Individual Building Successes

While a building label provides a static indication of building performance, a dashboard is meant to describe a more dynamic or real-time indication.

The concept of the dashboard is used to highlight the energy consumption of a given building and can support the successful application of NZEB technology and to provide feedback on the actual performance of the building. Static dashboards provide a snapshot of building performance and are applicable to building certification, while dynamic or real-time dashboards involve data collection and reporting of the information. The objective is to provide feedback to the building owners and occupants on the performance as well as to provide standardized metrics for reporting the building's performance to a larger audience. In fact, such a real-time display of energy consumption and other performance parameters is envisioned for the ASHRAE headquarters project, with online access to the data.

Such dashboards have been developed for many other projects. The idea being presented here is to combine various meters and sensors with data logging software and a graphic display to show how the building is performing at a moment in time, over some recent time interval, or over the long term. Such performance can be compared graphically with design values, requirements from codes and standards, expected performance in similar buildings, and past performance of the building in question.

If such a dashboard was centrally administered it would have the advantage of allowing for the collection of energy use and energy production data for the spectrum of participating projects. This could become the framework for a very useful database, both for understanding the current performance of the monitored projects as well as comparison to CBECS data sets. In this way the dashboard would truly be analogous to the automobile, in that the information displayed would assist in driving the building industry toward the NZEB destination.

Regardless, the objective of data collection is to document improvements in the building stock. One idea for presenting this information is to develop a high performance or green building subset of CBECS (Energy Information Agency's Commercial Building Energy Consumption Survey), i.e., GBECS.

Given an approach to displaying this information, the next question is what metrics to display. The specific parameters that are displayed on such a dashboard are always going to be building-specific to some degree, and if ASHRAE is going to propose a specific dashboard view, then additional discussion will be needed. The following list attempts to present some of the options:

Energy consumption:

- Real-time, integrated over recent days/weeks/months, annual
- Broken down by use, e.g., fans, chillers, lighting, elevators, etc.
- Reference values: CBECS, design value, etc.
- Local utility demand; prices

System status:

- Airflow rates, including outdoor air intake
- Airstream temperatures

Level of service:

- Thermal comfort: dry-bulb temperature, RH, air speed; multiple locations in the building
- Indoor pollutant levels: e.g., carbon dioxide, fine and coarse particles
- Occupancy

Outdoor conditions:

- Air temperature
- Wind speed and direction
- Ambient pollutant levels: fine and coarse particles, ozone, etc. (this may available from EPA NAAQS monitoring locations)
- Non-energy building performance
- Water usage indoors and outdoors
- Sewage outflow

These concepts share the objective of trying to reduce the energy consumption of the building stock and to collect data that documents this reduction over time through CBECS and other measures. To that end, it may be interesting to consider developing a high-performance or Green Building subset of CBECS. How about GBECS?

Energy Conservation in the Built Environment

Energy conservation in the built environment comes first and is something that ASHRAE can influence very directly.

Two major elements that we can address are new construction and the existing building stock. It is somewhat bothersome that most of our effort is directed at new construction, which is only a small slice of the total energy pie. We have, however, an opportunity to highlight the relative contributions and have impact on both design and operation. If CO_2/GWP emissions are the desired end result, perhaps it is not significant to try to segregate. Between energy consumption and emissions, there is the politics of power generation. ASHRAE's influence in this arena may be small, but the impact is huge (e.g., consider nuclear power generation). While ASHRAE may have little influence on the politics, it is important to understand what could be.

An initial list of attributes would include the following, each as a function of time:

- Energy consumption per area in new construction (without consideration of plug loads which ASHRAE cannot influence)
- Energy consumption per area in existing building stock (again without plug loads)
- Energy consumption per area (new construction + existing stock—sum of above two)
- Emissions per unit of energy consumption vs. projected power generation policy
- Emissions per area (new construction + existing stock)

In addition to the attributes above, an assessment of the economics (where to get the biggest bang for the buck) might be appropriate. Also some proposal to address the existing building stock would seem necessary, although not easy and not cheap. These may suggest additional metrics.

Products Needed for Net Zero Energy Buildings

A plan to reach NZEBs requires good information made available to motivated practitioners. Development of publications, research topics, and education programs identified below will promote this effort.

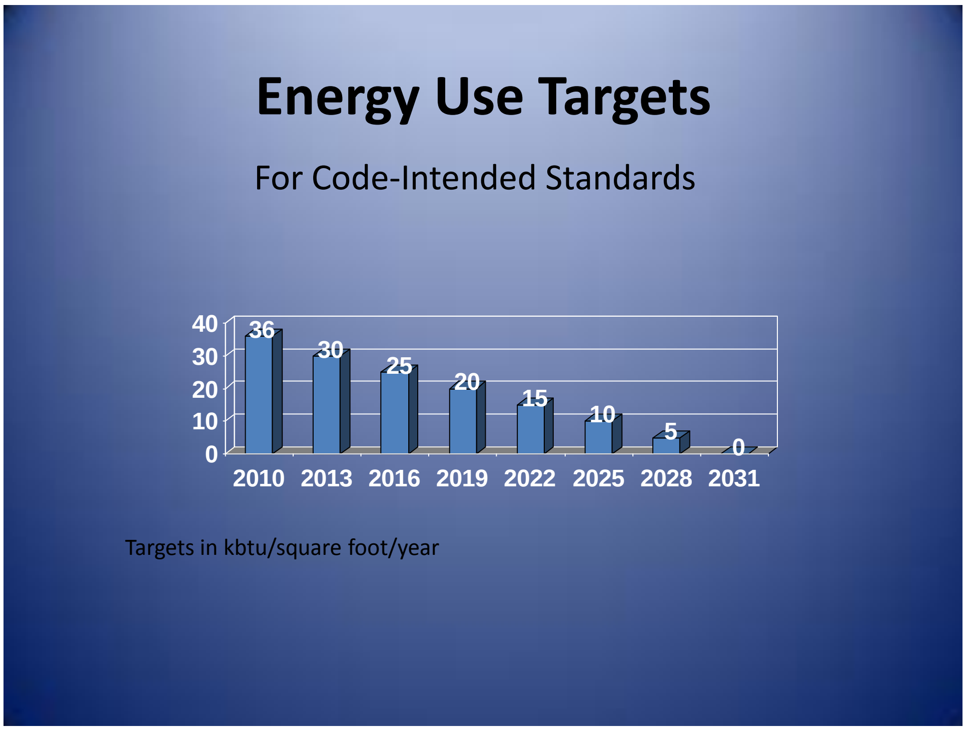
Publications

ASHRAE Handbook

The *ASHRAE Handbook* series and the *ASHRAE Terminology of HVAC&R* should be reviewed to ensure that terms relative to NZEBs are clearly defined. A chapter on "Fundamentals of Sustainability" should be added under the direction of TC 2.8. This chapter should include information on what it takes to meet NZEBs. An example of this is that it will require daylighting strategies to get to 70% energy savings. It is also noted that an important aspect of NZEB will be integrated building design. A chapter under the direction of TC 7.1 is planned for the *2007 ASHRAE Handbook—Applications*.

Standards and Guidelines

While it is acknowledged that standards are for a mature body of knowledge, and that an NZEB is not a mature body of knowledge, there are components of that body of knowledge whose aspects should be included in our standards and guidelines. Among these is method of testing for NZEBs. Additionally, the scopes of Standards 90.1 and 189P should be expanded to include plug loads, cooking equipment, and refrigeration loads.



Special Publications

The AEDG series is currently planned to be a series of guides that provide 30% energy reduction guidance, 50% energy reduction guidance, and 70% energy guidance. We recommend that the 70% energy reduction guides scheduled for completion by 2015 be modified to become net zero energy design guides. These guides would offer strategies that provide design guidance for 70% energy savings and strategies for on-site renewable energy concepts that result in NZEBs.

Education

Continuing education for building designers, contractors, operators, owners, and occupants is necessary for NZEB to become a reality. To that end, ASHRAE must expand its educational offerings to ensure that its members and others have the necessary tools to be the source for knowledge on NZEBs. In order for this to happen, ASHRAE's Technical Committees must continue to develop state-of-the-art content for its suite of educational tools. In order to ensure maximum coverage, NZEB offerings should be developed in the eLearning modules; short courses, professional development series, and those new technologies for information dissemination, such as podcasts, should also be developed.

Certification Programs

Certification will become an important aspect for ASHRAE members to market themselves as NZEB-certified designers. The certification for the Sustainability Design Professionals program should be expanded to include certification for NZEB design professionals as the body of knowledge is formed and design guidance becomes available.

Research

Research must be completed in support of NZEBs in order to provide design guidance by 2020. Topics span all aspects of the building industry, including the building envelope, mechanical equipment and controls, lighting systems, and controls and service water heating and controls. In addition to these building related aspects, the design process must be carefully examined to ensure NZEB. ASHRAE must partner with other organizations, such as the USGBC Research Committee, to ensure the timely completion of these tasks. Additionally, within ASHRAE, this information will be important for the Research Advisory Panel (RAP) as they prepare the Research Strategic Plan (RSP). Specific research topics are prioritized and listed in the appendix of this report. Following are examples of some of the highest priority research topics necessary to provide design guidance for NZEB.

Building Envelope

The building envelope should be designed to minimize buildings' HVAC and lighting loads. For example, on a residential scale, the U.S. Department of Energy Research Toward Zero Energy Homes demonstrates methods to get to 70% efficiency and recommends roof areas with a given efficiency of solar domestic hot water (SDHW) and photovoltaics (PV) to meet the remaining loads. This methodology can be applied to commercial typologies as well. For buildings with high lighting requirements, daylighting needs to be a primary façade element; similarly, cooling or ventilation loads should influence envelope design. Some areas to develop include:

Dynamic "Advanced" Facades
Glazing
Frames
Daylight Devices
Envelope airtightness

Design Tools

There is a need for more accurate geometry for architectural models imported to energy simulation programs. Actively pursue standardizing interoperability between software tools and developing software tools that can accurately model NZEBs. More specific recommendations are included in the appendix.

Small Power/Plug Loads/Miscellaneous Loads

Since these loads are not regulated in Standard 90.1 and also not under the control of the designer, they tend to be neglected. It is important that an evaluation of plug, process, cooking, and refrigeration loads are factored in to the NZEB calculation. More specific recommendations are included in the appendix.

Operating Issues

There is a need to reduce constraints imposed by the structure of the current building industry. Maintainability, simplicity, ease of operation, and controllability are important considerations to ensure optimal operation of an NZEB.

Nonbuilding-Specific Research

The following three sections discuss crucial research items that are not building-specific but will impact the success of ASHRAE 2020. They address: restructuring professional relationships and incentives in the building industry to encourage energy efficiency, researching the relationship between building energy and source energy to effectively reduce overall environmental impact, and coordinating building systems with the operation of larger regional systems.

1. Alleviate constraints imposed by current industry structure and incentives.

The structure of the current building discourages energy efficiency.

The numerous players involved (architects, engineers, specifiers, purchasers, money lenders, owners, and tenants) often have different and conflicting financial motivations that discourage investment in innovative energy-efficient building designs, and favor the purchase and installation of oversized HVAC systems even after energy-efficient measures have been made in the design of the envelope and insulation. Identifying and understanding these opposing incentives are a high priority because they determine the ability of building professionals to champion energy-efficient changes.

How to change and motivate engineers, developers, design professionals, and clients to excel:

A. Establish a fee structure based on performance rather than equipment cost.

Bids may be structured in several parts: one component may cover the costs for designing a "baseline" efficiency system; other components can reward designers and engineers for incremental reductions in energy costs throughout the life of the system or in total life-cycle costs. Fees can be contingent on performance as guaranteed by design specifications, and distributed after corroboration by commissioning documents or energy bills.

Utilities often reward customers with rebates for installing efficient equipment. Consider a "built-in" design royalty that passes along a percentage of these "hardware" rebates to the engineer or architect as compensation for their "soft" design contributions.

B. Educate current students to meet emerging standards and issues.

Educate the next generation of practitioners to make high-performance standard practice.

Sponsor outreach and educational programs that promotes the integration of building science and energy systems into the curricula of architecture and engineering schools. Support curricula that include energy-efficiency courses in the core of requirements, and allow students the flexibility to take additional electives in energy efficiency. Raise the standards of acceptable maximum EUIs on an annual basis to address the vision 2020 goals.

C. Educate developers and financiers.

Developers and financiers have incentive to minimize capital costs and maximize resale potential. They are typically less motivated to invest in energy-efficient systems because they currently do not benefit from the future energy savings. Reform accounting methods so that discounted rates can accurately portray the capital costs of superior systems. Show lawyers, commercial lenders, investment advisors, appraisers, and developers seminal issues such as:

i. Avoided operational energy costs can enhance retail market value.

ii. Capital costs reduced by proper HVAC sizing may be able to create cost neutral or capital cost savings through optimizing entire building systems. Building elements optimized in isolation tend to increase costs and "pessimize" the system, whereas optimizing whole systems helps realize increased efficiencies while reducing cost.

iii. Any extra capital investments in superior HVAC systems can be paid back in savings from improved occupant productivity because the present-value of capital costs for mechanical systems are dwarfed by the present-value of employee salaries.

D. Educate maintenance staff on the intent of technically advanced systems, and to manage and care for systems accordingly.

Time, budget, training, and ease of operation (including simplicity of computerized interfaces) are considerations that should be factored into system cost calculations.

E. Promote interdisciplinary design, i.e., mechanical, electrical, and architectural.

Mechanical, electrical, and architectural expertise are typically provided by different sources, and HVAC systems are often designed as an afterthought to existing architectural plans. This disconnect is reinforced by lack of experience in integrated design, fear of taking on new financial risks by changing design processes that "work," and conflicting ideas and metrics for what makes a "high-performance" building.

One strategy to promote interdisciplinary design is to use total present-valued life-cycle occupancy cost as a financial objective. This can help to align design goals, make the case for early integration of mechanical and electrical input, and encourage communication between disciplines that currently emphasize exclusive "specialization" over transparency and information sharing.

F. Educate the client regarding net zero, and encouraging the demand.

i. Discourage oversizing of HVAC systems for the sake of accommodating possible future tenants who may (or may not) have higher load requirements. Provide for tenant flexibility and save money by specifying pads and stub-outs for future add-ons, thereby avoiding the initial capital and operating energy costs associated with unnecessarily oversized components.

ii. Raise awareness of different fee structures that can reward efficient designs.

G. Encourage utilities to pay error-and-omissions insurance for new buildings incorporating unconventional designs.

Reduce the risk for designers who currently sacrifice efficiency for fear of incurred liability charges.

H. Establish contracts that include a complete set of specifications, and provide for full commissioning, operations and maintenance training, and documentation.

Specifications should call out all equipment, including sizes of pipes and wires and type of insulation tape. Be specific about the make of products and avoid phrases like "or equal," "high-efficiency motor," and "low-emissivity glass."

I. Encourage the adoption of Standard 90.1 type codes.

J. Design a "cost-neutral" high-performance building.

This may include a systems approach to LCA and bundling efficiency packages to optimize both cost and energy performance. It also implies active integrated engagement of the engineering team in the early schematic building design to coordinate building mechanical costs and building design optimization (i.e., investments in more efficient glazing can enable downsizing and reduced costs in HVAC system).

K. Structure leases so energy-saving retrofits can benefit both tenant and owner.

Promote cost-effective submetering. Favor requirements to provide performance-based ASHRAE comfort conditions as opposed to support for outdated lighting and heating loads.

2. Establish the boundaries of the building.

The following items may be addressed in collaboration with the USGBC.

A. Source energy should be included if the primary motivation is to reduce the impact of building energy consumption on global warming.

B. ASHRAE can develop a standard for quantifying regional greenhouse gas (GHG) emissions that enable individuals to:

i. Arrive at a figure for the amount of nonrenewable energy used by a building.

ii. Identify regional greenhouse gas intensity coefficients to determine a building's net carbon emissions as well as source energy impact. This coefficient should address distance/transmission loss issues as well as source energy type. It should also address time of day dependence on energy conservation rates. Use of this coefficient will allow conversion between energy use, source, and emissions.

C. ASHRAE to copublish EIA energy generation fuel type data.

D. Renewable Energy Credits (RECs)

ASHRAE 2020 should promote demand-side reduction and the use of on-site renewable sources by stipulating that a minimum of 50% of building energy be brought to net zero through efficient building techniques and on-site generation. RECs should not be permitted to offset building nonrenewable energy use or carbon emissions for more than 50% of the building's net energy consumption.

i. ASHRAE 2020 should be clear about the motivations for purchasing RECS or offsets (i.e., promoting the use of renewable energy, offsetting carbon emissions, or both) and provide a defined method for converting units of energy used to the corresponding REC or offset units.

Net nonrenewable energy use (calculated in kilowatt-hours) can be offset with RECs that are certified for "additionality" by acceptable authorities.

GHG emissions (calculated in tons of CO_2 equivalent) can be brought to net zero by carbon offsets certified for additionality by acceptable authorities.

ii. Specify standards for offsets and RECs based on: demonstrated additionality, credible determination of offset project's baseline emissions, credible quantification of offset project's GHG emissions reductions, permanence of offsets, clear ownership of project reductions, and verification and registration of offsets (to reduce the possibility of multiple ownership and sales). Provide a list of acceptable certification programs (i.e., atmosphere, Carbon Neutral Co., Climate Care, Climate Trust, co2balance, etc.).

E. Potable water, wastewater, and utility connectivity: Water use for a building must be included in the building energy utilization index (EUI).

This is done by quantifying the water used or produced by the building, and converting that amount to its energy equivalent. Buildings that generate potable water (or clean sewage) in excess of their use should be credited through net metering.

Currently, projects that include on-site wastewater treatment are essentially penalized (e.g., Oberlin's Lewis Center). Others use potable water and sewage systems and impose loads that are not accounted for in a typical energy analysis.

F. Embodied Energy

Effort should be made to account for and reduce the energy embodied through construction. Standardized databases should be expanded with applications created to assist designers in making decisions about embodied energy.

3. Integration of Building with Larger Systems

A. ASHRAE 2020 should target reduced baseload as well as peak utility loads.

Strategies include:

i. Creation of real-time load shedding information systems capable of integrating demand and loads in a two-way condition. This includes the broader definition and generation of the "smart grid."

ii. Broad adoption of net metering systems that encourage distributed generation in a manner that is profitable for all parties.

iii. Development of building based electrical (or energy) storage systems that provide dispatchable energy (including the "plug-in hybrid" systems).

iv. Generation and adoption of policy at the utility level that encourages the above, including smart residential and commercial utility interface kit sets.

Marketing Communications Plan

ASHRAE and its activities are well known within the HVAC&R industry. As the circle of groups involved in the financing, development, design, construction, and operation of buildings expands, eventually including building occupants and government regulators, awareness of ASHRAE diminishes.

The strategy to promote NZEB technology, and ultimately the construction of NZEBs, will have four prongs:

- Raise awareness within the building community of the feasibility for and the benefits of constructing and NZEBs.
- Establish demand for building certification and professional accreditation within the building community.
- Promote the sale of NZEB-related publications and educational products.
- Build general public awareness that the technologies of building heating and cooling and industrial processes can be compatible with sustainable buildings.

Raising Awareness in the Building Community

Audiences for this marketing strategy will be communities consisting of architects, code officials, building developers, the design-build professionals, and manufacturers.

The two major vehicles used to reach these audiences will be news and articles in trade publications and a Green Team Resource Group that will serve as a speakers' bureau for conferences and association meetings in the industry. This response team will also be prepared to share messaging when opportunities arise in the media.

A major initiative that will be explored is the creation of an NZEB Technology Conference. This conference will present invited speakers rather than assembling a program through a call for papers. The purpose of the conference will be to educate practitioners, government officials, and developers on the benefits of NZEB. Both the technical side of NZEB will be explored as well as financing and construction.

Establishing Demand for Certification and Accreditation

The most important and challenging aspect of the marketing communications effort will be to create demand for building certification and accreditation of professional NZEB services. This needs to be accomplished by building value in these programs and effectively communicating it. Successful completion of this effort will support execution of the three other prongs of the strategy.

The steps to be followed for execution are:

a. Identification of market segments that make purchasing decisions related to NZEB construction and services.
b. Placement of "success" stories in communication vehicles that serve those audiences.
c. Targeted advertising campaigns in communication vehicles that serve those audiences.
d. Development of tools that can be used by owners of NZEB-certified buildings and by accredited professionals that will allow them to bring attention to the respective programs.
e. Promotion by ASHRAE that will result in business opportunities for persons earning accreditation, and promotion by ASHRAE to the general public that will draw attention to building owners and developers who support NZEB technology.

Promote Publications and Educational Products

A full suite of publications and educational products will be developed in support on NZEB technology. Promotion plans will be developed for these products, grouping them for efficient use of the marketing budget.

A key objective of the marketing communication strategy is to make the effort revenue neutral to ASHRAE through increased sales.

The primary market will be the ASHRAE membership. But professionals in all related disciplines will also be targeted with special emphasis on:

- Lighting designers
- Architects
- Contractors
- Owner's operating staffs

A concerted effort will be to engage in cooperative marketing efforts with the associations serving these non-ASHRAE audiences.

Within ASHRAE, a program track promoting use of and engaging in discussion about NEZB products will be held at ASHRAE meeting. Other association partners will be encouraged to organize similar tracks at their meetings.

Build General Public Awareness

It may be questioned whether any investment to reach the general public is an efficient use of resources. The ultimate beneficiary of

NZEBs, however, is the public, and the public—as building occupants and through government—should be recognized as a force for the implementation of NZEBs.

Because the effort to reach the public will be so large, it is essential that ASHRAE not undertake this effort alone. An effort should be made to obtain funding from a foundation interested in advancing technology for environmental benefit, and this also should be done in partnership with the other associations contributing to the effort, such as USGBC, AIA, BOMA, and IESNA.

Activities that will be pursued include:

- PBS or NPR underwriting;
- Development of educational programming for secondary schools, perhaps based on adaptation of the ASHRAE eLearning module for NZEB;
- Placement of articles in media dealing with office environments, such as the publications for chief financial officers, human resource managers, office administrators, etc.

The Plan for Existing Products

The code arena has many different versions (issue dates) of codes being used in different jurisdictions. Similarly, ASHRAE will likely need to have various versions available for an indefinite period of time of its publications related to NZEBs. This is similar to various versions of Standard 90.1, for example.

The following are fundamental points regarding ASHRAE NZEB documents:

- The ASHRAE documents should be referenced to a fixed baseline, ANSI/ASHRAE/IESNA Standard 90.1-1999.

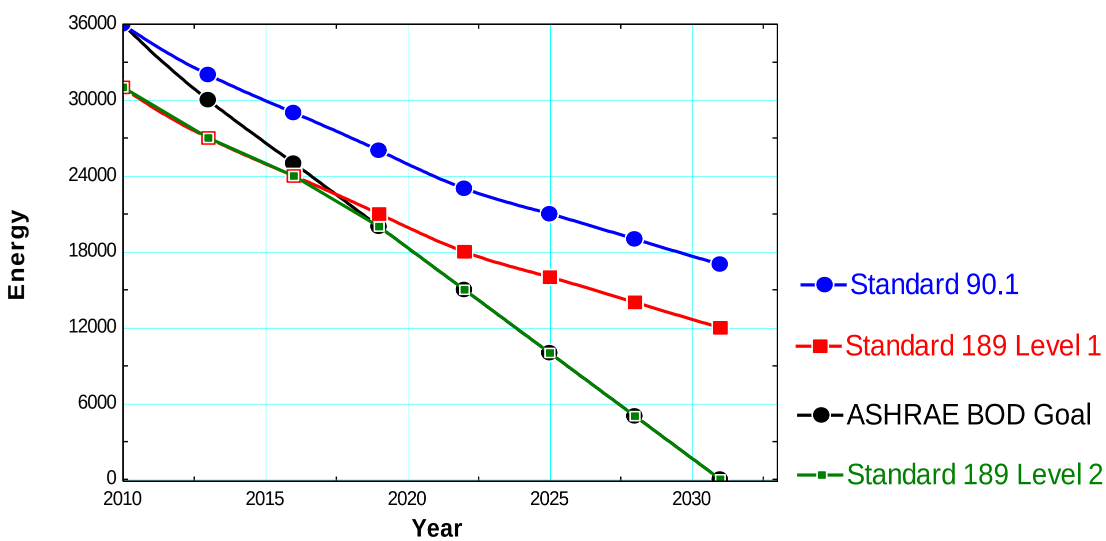
- The document name should be tied to our ASHRAE baseline. AEDGs should give a percentage reduction from the baseline and the year of issue. For example, the title of an AEDG will not change once it is published, so a 30% AEDG remains a 30% guide. The next version would be more stringent—say, 40% or 50%. Each guide would be referenced to Standard 90.1-1999 as representing the "turn of the millennium." Thus, as new versions of Standard 90.1 (and Standard 189) are published, there will be a conversion given that identifies the percentage relative to the new version of the standard. For example the 30% small retail guide savings relative to Standard 90.1-2004 are seven percentage points less than when compared to Standard 90.1-1999. Older versions will be made available in digital format with the recommendation that the user update to current versions.

- When the new versions of Standards 90.1 and 189 are issued, the AEDGs and other energy-related documents need to be updated. The older versions would still be available even if printed by demand (downloadable from the Web and in print)—this how you buy ISO standards today. This also saves on mailing cost.

- The Standard 90.1 and 189 Energy Target Direction approved by the ASHRAE Board of Directors in April 2007 as shown below should be followed.

- Technology Council should take the lead in making sure that NZEB design documents are technical-content coordinated and coherent. This will require a review of *Handbooks*, special publications, standards, and guidelines.

- Products should be made available in the market as an integrated suite of products—for example, the Commercial Energy-Efficiency Suite (Standard 90.1, 90.1 Users Manual, and 5 50% AEDGs and e-Learning modules).



Volunteer Coordination

Direction 1 of the ASHRAE Strategic Plan states that ASHRAE will lead the advancement in sustainable building design and operation. Further, strategy 1.2 states that ASHRAE will lead the drive toward the design, construction, and operation of NZEBs through research, publications, and education.

To accomplish this, coordination strategies will need to cut across all councils. Technology Council, the Technical Activities Committee (TAC), the Research Administration Committee (RAC), the Standards Committee, and, to some extent, the Refrigeration Committee, plus many technical committees and standard project committees, will have projects that move ASHRAE forward to net zero energy use. Technology Council has formed a committee within the council called *SP2006* to coordinate the activities within the council on the various strategic plan strategies within Direction 1. Each strategy has been assigned a champion, who is a member of Technology Council, whose responsibility is to track the action plans developed to advance the strategies and to ensure timely completion of the various tasks and work plans developed to further that advancement. Specifically relative to strategy 1.2, Technology Council should take care in the selection of the champion to ensure continuity over the years so as not to lose the institutional memory required to make Vision 2020 a reality. Technology Council should consider forming a Task Group whose focus is strictly NZEBs. In addition to this, Technology Council should consider adding a focus point in its Members First Newsletter on NZEB design, construction, and operation.

Technology Council and its committees have the research point in the strategy stating that ASHRAE will lead the drive toward the design, construction, and operation of NZEBs through research, publications, and education. The Publication and Education Council (PEC) has the responsibility for the publishing of the technical information related to net zero energy and for producing education programs for training of building professionals. The Handbook Committee, Professional Development Committee, Publications Committee, and the Certification Committee all will need to play a role in their respective activities in the move to net zero energy use in facilities. As research projects are completed and results are published, all of the aforementioned committees will play a role in disseminating the information gained to ASHRAE members and the building industry.

The committees of PEC will also develop new topics for continuing education and professional development programs, and must work with ASHRAE's Technical Committees to develop the content for these programs.

In order to stay ahead of developments, Technology Council and PEC should communicate regularly regarding strategy 1.2 actions plans, schedules, and results. To ensure this communication, both councils should consider appointing a champion for this strategy that reports progress to their respective councils. These champions would work together and establish routine communication so that both councils are aware of work being done by both councils and their respective standing technical and project committees.

Members Council and the Chapter Technology Transfer Committee (CTTC) will also play a vital role in the move to net zero energy use in facilities. CTTC should be on point for outreach to ASHRAE chapter members regarding progress being made in the net zero energy facilities design, construction, and operation. The first need will be to convince our members and other stakeholders of the importance of this work. Working with the Publications Committee, this outreach should be done through publication of articles in *ASHRAE Journal* and other periodicals and through chapter meeting materials designed to get the message across. As progress is made through research, the message can then be updated so that the broadest possible spectrum of members and stakeholders is aware of that progress.

All three councils will need to work together to develop the materials required to deliver this message. To that end, both Technology Council and PEC should appoint liaisons to CTTC and Members Council whose responsibility is to keep CTTC informed of the progress being made toward net zero energy usage in facilities.

Appendix
ASHRAE 2020:
NZEB Research Topics

Following is a more detailed listing of possible research topics needs to provide net zero energy design guidance:

ASHRAE Research Topics—Priority 1

Topics listed as Priority 1 fall within ASHRAE's core competency.

Building Envelope

The building envelope should be designed to match buildings loads and resources. For example, on a residential scale the U.S. Department of Energy Research Toward Zero Energy Homes demonstrates methods to get to 70% efficiency and recommends roof areas with a given efficiency of solar domestic hot water (SDHW) and photovoltaics (PV) to meet the remaining loads. This methodology can be applied to commercial typologies as well. For buildings with high lighting requirements, daylighting needs to be a primary façade element; similarly, cooling or ventilation loads should influence envelope design. Some areas to develop include:

a. Dynamic "advanced" facades
b. Glazing
c. Frames
d. Daylight devices
e. Envelope airtightness

Design Tools

There is a need for more accurate geometry for architectural models imported to energy simulation programs. Actively pursue standardizing interoperability between software tools and developing software tools that can accurately model net zero energy buildings (NZEBs).

Small Power/Plug Loads/Miscellaneous Loads

Since these loads are not regulated in Standard 90.1 and also not under the control of the designer, they tend to be neglected. It is important that an evaluation of process, cooking, and refrigeration loads are factored in to the NZEB calculation.

Operating Issues

There is a need to reduce constraints imposed by the structure of the current building industry. Maintainability, simplicity, ease of operation, and controllability are important considerations to ensure optimal operation of an NZEB.

ASHRAE Research Topics—Priority 2

Some Priority 2 research topics do not fall under ASHRAE's core expertise. They should be addressed by working with the indicated organizations.

Design Tools

The following may be pursued with assistance from IESNA.

a. Daylighting simulation and evaluation tools
b. Ability to size HVAC systems accounting for daylighting technologies including thermal storage
c. Renewable energy integration tools

Electrical Power

ASHRAE should work with IEEE and others to address these issues.

a. Demand control and load shedding
b. Electrical equipment efficiency
c. Integrating renewable generation (DC current) in building electrical systems
d. Small scale cogeneration integration
e. Electrical storage
f. Net metering standards

Service Water Heating

These items are not addressed by the Research Strategic Plan (RSP) but will impact NZEBs.

a. Research project/new standards
b. Domestic Hot Water (DHW) conserving fixtures
c. Instantaneous DHW systems

ASHRAE Research Topics—Priority 3

Some Priority 3 research topics do not fall under ASHRAE's core expertise. They should be addressed by working with the indicated organizations.

Climate Typology

Copublish solar and wind data with NREL solar databases. There is a need for better index of clear/cloudy skies and to understand the implications to design.

Topics Addressed Outside of ASHRAE Research

The following topics are important to the ASHRAE 2020 initiative and are being pursued, or should be pursued, by other committees within ASHRAE, such as the Research Advisory Panel impaneled to development the next generation Research Strategic Plan (RSP) and the Advanced Energy Design Guide Steering Committee. Continued attention should be given to these topics to enhance net zero energy design guidance.

Climate Typology

a. Develop basic recommendations for each of the ASHRAE climate zones to simplify "packages" of recommendations for designers (currently being addressed by AEDG).
b. "Advanced Energy Design Guide" approach for larger facilities to hit efficiency improvements of 70% relative to baseline (currently being addressed by AEDG).
c. Better envelope standards guidance per location and orientation (currently being addressed by SSPC 90.1).
d. Consider the extension of the comfort zone (should be addressed by SSPC 55).

Design Tools

a. Provide building balance point tools for use in the schematic design stage to match building envelope to climate conditions (currently addressed in RSP).
b. Energy simulation for Standard 90.1 evaluation.

HVAC

HVAC is currently addressed in the ASHRAE Research Strategic Plan.

a. Natural ventilation design standards and guidance
b. Alternative HVAC distribution
c. Boiler efficiency
d. Chiller efficiency
e. Increase the delivered efficiency of heating, cooling, and ventilation perhaps with a shift from air to water as the medium for energy
f. Consider total combined energy efficiency: fan energy, electrical distribution, and gas distribution

Lighting

Lighting is currently addressed by IESNA.

a. Lighting system design with emphasis on lighting quality, task lighting, and sample packages of lighting system designs that reduce the required lighting power density
b. Lighting controls
c. Lamp technology
d. New lamp materials (photonic crystals)