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Advanced Energy Design Guides Scoping Committee for 50 % Approach to Net Zero Energy Use in Commercial Buildings 12/07/06

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EXECUTIVE SUMMARY

ASHRAE, in conjunction with its partners AIA, IESNA and USGBC is generating a series of Advanced Energy Design Guides (AEDG) for the commercial building sector. The AEDG Steering Committee formed a Scoping Study committee and charged it with developing the background necessary to develop a 50 % energy reduction guideline.

In this report, a review and evaluation of existing low energy buildings are carried out. These buildings, together with supporting studies demonstrate that buildings can approach a net zero energy use using current technology. The available design approaches and measures that have the potential to produce net zero-energy use as well as some of the associated cost issues are identified.

An Integrated Design Process, which is necessary to obtain a net zero-energy use building, is described. A plan for producing an AEDG in a timely fashion is presented. This report is expected to provide the information necessary to allow the Guide Project Committee to produce Guides to approach Net Zero Energy Use in Buildings.

BACKGROUND

ASHRAE, in conjunction with its partners AIA, IESNA and USGBC, is generating a series of Advanced Energy Design Guides (AEDG) for the commercial building sector. Currently, Guides are being developed that target 30% energy savings relative to buildings designed to meet the requirements in energy standards in effect at the turn of the millennium (Standard 90.1-1999). The partnership initially planned to follow this series with Guides that target 50% and, subsequently, 70 % energy savings.

In September, 2005, the AEDG Steering Committee formed a Scoping Study committee to develop the background necessary to develop a guideline for a 50 % energy reduction guideline. The specific charge to the Scoping Study Committee was to a) document what is known about achieving highly energy efficient buildings, b) determine what needs to be developed to produce AEDGs for different classes of buildings in different climates, c) identify specific information, tools, and research needs, and d) propose a plan for creating an AEDG in a timely fashion (Appendix 1).

During the Scoping Committee discussions, the philosophy of the project changed from a “50 % energy reduction” to a “50 % approach to net zero energy use.” A net zero-energy use building is a building that uses equal or less energy than it produces on an annual basis. Further, the Scoping Committee realized that there is a continuum in energy reduction from the current practice to a net zero energy building. The goal of the Scoping Committee has become to provide the information to develop Guides for Net Zero Energy Buildings (termed “Guides” in this report).

The magnitude of the approach to net zero energy use for a building depends on the base line energy use. There are several possible baselines to use in evaluating energy use, and the approach to net zero energy use depends on the selection. The amount of energy reduction also depends on whether the approach is to net zero site or source energy use. The Scoping Committee discussed these issues and has made preliminary recommendations.

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The immediate goal of the Guides would be to present measures that will allow buildings to achieve a 50 % approach to net zero energy use by 2010. The criteria that the Committee used for selecting measures was that they were either currently available or would become readily available in the next five years. The measures selected were not “sole source” but available from more than one vendor, and expected to provide the same amenities at a cost equal to or lower than current practice. The implementation of the measures recommended in the Guides is expected to lead to improvements in these technologies over time through a natural engineering development process.

Achieving the desired performance goal will require more than simply the substitution or adoption of new technologies and systems. It will require at least three changes in practice: (1) a shift in design process to utilize integrated design procedures starting early in the design process, (2) rigorous attention to best practice in construction and commissioning, and (3) improved maintenance and operating procedures in order to provide sustainable savings over time. Many of these needed practices are used today by leading design firms and owners but do not yet constitute standard practice.

It is anticipated that there will be increased design costs incurred in following the recommendations in the Guides. Successful use of integrated design methods requires a committed owner and an experienced design team who can weigh the energy cost savings against the capital costs for every measure. Additionally, there will be potential savings in capital costs, definite savings in energy costs, and probable lower life cycle costs. An integrated design would result in major improvements in the quality of the indoor environment, with better control of temperature, humidity, and ventilation rates than conventional design. The resulting building will then provide comparable or better amenities as conventional construction at the same or reduced cost.

The cost of energy reduction measures needs to be put in perspective. The construction cost for a new building is at least \$ 150/ft², while the cost of the HVAC system is typically \$ 25/ft² or less. Even a 25 % increase in the cost of the HVAC system is comparable to only a 3 % increase in the building cost. A 25 % increase in the cost of the HVAC system that produces a 50 % reduction in energy use would yield savings of about \$ 0.50/ft²- year. The accrued savings would pay for a 3 % increase in building (due to 25 % increase in HVAC costs) in 10 years and continue to produce savings for the life of the building. Energy reduction methods can be cost effective.

This final report of the Scoping Committee contains the following:

- A review and evaluation of existing buildings and studies that demonstrate a significant approach to net zero energy use.
- Identification of the available design approaches and measures that have the potential to produce an approach to net zero-energy use.
- Identification of the additional data and research necessary to achieve an approach net zero energy use.
- A description of the process necessary to obtain a net zero-energy use building.
- A plan for producing an AEDG in a timely fashion.

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DEFINITION OF A NET ZERO ENERGY BUILDING

The development of Guides to facilitate the construction of Net Zero Energy Buildings is consistent with the ASHRAE Strategic Plan. One of the four Directions for the Plan is that “ASHRAE will lead the advancement of sustainable building design and operations.” A Net Zero Energy Building would be sustainable in terms of the energy required to allow the functions in the building to be performed. A “net zero energy” building would not, on average over a year, place any additional demands on the U.S. energy sector. It would supply from renewable sources the equivalent of the energy required to effectively operate the building in the manner needed by the occupants.

The concept of Net Zero Energy is simple, but needs to be carefully defined. The time period over which net zero energy use is achieved is taken as a year. Connection to the electrical grid is also important to allow excess electric generation at some periods to be distributed and deficiencies made up. Four relevant energy consumption criteria are (from Torcellini et al., 2006):

- Net Zero Site Energy, defined as a building for which the generation at the site equals the consumption at the site over the course of a year. This criterion does not distinguish between the energy values of electricity, natural gas, or oil. It can be readily evaluated through metering. The use of this criterion is consistent with the 30 % Energy Reduction Guides already developed.
- Net Zero Source Energy. For this criterion the generation equals the consumption based on energy consumption at the source. This is a more global view in which site electrical generation offsets site and power plant energy consumption. The source evaluation accounts for the different source energy values of gas and electricity, but requires using regional conversion efficiencies for fuel to electricity to make the evaluation.
- Net Zero Energy Cost, defined as the cost of energy at the site. This criterion appeals to the owner or operator in that the cost is readily measured. However, the criterion may be difficult to apply in times of changes in utility rates. Cost includes demand charges, which encourages storage technologies.
- Net Zero Energy Emission, defined as building that produces at least as much emissions free renewable energy as it uses from emission-producing energy sources.

The committee did not select one of these definitions, and did not select measures with one of these criteria in mind. The selection of measures was based on significant reductions in energy use, which would reduce energy at both the site and the source, reduce the cost of operation, and reduce emissions. It will be important that Guide Project Committee select one of these criteria at an early stage in the development of the Guides. The value of measures, especially ones that use different fuels (i.e. gas or electricity) is very much dependent on the choice.

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POTENTIAL FOR ACHIEVING A NET ZERO SITE ENERGY BUILDING

There is a theoretical basis for assuming that a Net Zero Energy building is feasible. NREL has conducted a building sector analysis to evaluate a number of promising technologies (Griffith et al., June 2006). They created more than 5000 models for all building types based on the 1999 CBECS data set. Characteristic parameters were used to describe these models and the building energy use was then calibrated to the CBECS data set. These models were then exercised with different technology options in different regions of the US to determine the maximum site energy reductions possible (Appendix 2). Three of the scenarios are relevant to the Scoping Study:

Base Case Building: the reference building with 90.1- 2004 characteristics.

Base Case Building with PV: the reference building with PV panels having a 10 % efficiency covering 50 % of the total roof area.

Low/Zero Energy Building: a building in which aggressive technologies currently available (2005) were applied. These include daylighting, high efficiency lighting, superinsulation, central water-based high COP chillers, and VAV systems. The building had the same PV system as the base case.

The results of the study relevant to the Scoping Study are

- None of the current building stock achieved Net Zero Site Energy use. Five percent of the buildings under the Base Case with PV scenario and 23 % of the buildings under the Low/Zero Energy Building scenario achieved net zero energy use.
- The average net site energy savings for the sector as a whole were 44 % for the Base Case with PV and 82 % with the aggressive energy reduction strategies in the Low/Zero Energy Building scenario.
- The total aggregate energy reduction potential is greatest for those sectors in which the floor area is largest. Warehouses, office, and educational facilities have the largest floor areas and the potential for significant total energy savings in these sectors is large. The total floor area is lowest for health care, enclosed malls, and laboratories and so the potential total savings are lower.
- It is more difficult to reach Net Zero Site Energy in a heating climate than a cooling climate.
- Roughly one-half of the energy reductions are due to aggressive energy reduction strategies and one-half due to PV-generated electricity. Both efficiency measure and electricity generation are essential to reaching net zero energy use.

The overall conclusion from this study is that it is possible to achieve Net Zero Site Energy Use in some buildings for some situations. The implication is that the goal of a significant approach to net zero energy, on either a site or source basis, is feasible. There are no apparent technological barriers to achieving the desired energy reductions, but aggressive energy conservation strategies and energy generation are needed.

These conclusions are based on simulation studies and the ability to achieve the low to zero energy performance has not been demonstrated for significant numbers of actual commercial buildings. Further, the Scoping Committee does not believe that the extensive use of PV systems will be feasible in the time frame of the Guides.

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CURRENT HIGH PERFORMANCE BUILDINGS

In the last several years, more than 100 buildings have been constructed that approach or meet a goal of 50 % or less energy consumption. Although they represent a very small proportion of the 6 million or so US building stock, they are significant in what they have achieved. Some of these buildings have been carefully evaluated and monitored by outside groups, while for others the energy performance is only self-reported and not verified by third parties. The most important output from the reports on these buildings is a delineation of the techniques that were most successful in reducing energy use. The key studies are summarized below (See Appendix 3 for a more complete summary).

NREL/DOE Case Studies

Six buildings in which NREL worked with the owner in either designing or modifying an existing design and then monitoring the building performance have been intensively studied. A summary of the results is given in “Lessons Learned from Case Studies of Six High-Performance Buildings”, by Torcellini, et al., June 2006. A detailed description of the design process and the results for each building is available from the websites listed in the References.

For each building a simulated “Baseline Building” with characteristics of an ASHRAE Standard 90.1 (not always the same version) was created and calibrated using measured data. The model was then simulated and a large number of alternatives examined. The building was then constructed or modified based on the simulation results. Five of the buildings had PV systems installed on the roof. The performance of the “As Built” building was determined from monitoring the building over a one or two year period combined with a calibrated model. The “site energy savings” varied from 25 to 62 %, with an average of 42 %. The buildings were relatively small (13,000 to 42,000 ft²) and the average specific annual site energy use was 32 kBtu/ft².

A number of measures were employed in most of the buildings, including daylighting controlled in combination with high efficiency lighting; a high performance envelope (walls and windows); and distributions systems with VAV, variable capacity fans, and ERV controlled in combination with economizers. There were also a number of climate-specific techniques, such as natural ventilation, evaporative cooling, and passive solar, that would not be applicable in all climates or for all buildings. Even though this is a small data set, the lessons learned are instructive:

- Although there was intensive work at the design and construction phase, the buildings did not operate as designed. They used more energy and produced less from PV than was predicted. Some of the reasons are poor controls, overly optimistic design predictions about occupant behavior and acceptance of energy reduction measures, less than predicted energy savings due to daylighting, greater than expected plug loads, less than expected building insulation, and poorer performing PV systems than predicted.
- These problems occurred even though the design teams had the benefit of extensive consulting support during design and on-site monitoring to improve performance after construction, which are capabilities that are not available in typical buildings.
- An integrated control system is essential to operation of the daylighting and electrical illumination systems, the ventilation system, load management, and overall operation of the building.

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ASHRAE Technology Award buildings

Many of the ASHRAE Technology Award buildings are high performance buildings reported in the ASHRAE Journal. There is considerably less information available on the equipment, modifications, and performance than for the DOE/NREL buildings, and the energy use and savings are self-reported. Although the actual energy use was measured, the baseline performance was often not determined, and the savings are an estimate.

The six buildings listed in Appendix 3 represent a broader range of commercial buildings and are considerably larger than those of the DOE/NREL study, ranging from 45,000 to 379,000 ft². The reported energy savings range from 20 to 60 %, although the energy use varies from 50 to 174 kBtu/ft², which is significantly higher than the buildings of the NREL/DOE data set.

Some of the measures common to these Technology Award buildings were processing the ventilation air separately and employing an ERV and an economizer; variable capacity pumps, fans, chillers using VFD, multi-speed, and incremental capacity units; high efficiency lighting; and an EMCS for implementing control strategies, including demand management, optimization, and fault detection and diagnosis.

New Buildings Institute Website

The New Buildings Institute database contains buildings from the AIA, BetterBricks, CHPS, DOE, EERE, GGHC, LEED, and Natural Step databases. Each project was screened to determine whether it approached or met the threshold of 50% better than ASHRAE 90.1 – 2001. The energy savings were not referred to ASHRAE 90.1 specifically, but were defined as “better than a code minimum building.” Project savings estimates are self reported and based on a combination of modeling and measured energy data to determine baseline annual energy use. Many of the projects include a review of the modeling by a third party.

A total of 83 buildings are reported, and these are predominately office, education and medical/ lab buildings, with some housing, retail, assembly and warehouse buildings. The buildings were in most areas of the country, with the largest numbers in the Northeast and West coast regions. There are eight buildings in the heavy air-conditioning area of the Southeast, and seven buildings in the winter-dominated Midwest.

The median values for the floor area in a given sector cover a wide range from 10,000 to 170,000 ft², and the medium annual energy use for the sectors, excluding the warehouses (low use) and the medical laboratories (high use), ranged from 25 to 44 kBtu/ft².

The measures employed are instructive in developing the Guides, even though there is not information on the performance of the measures. The measures and the percent of buildings in which they were used were:

- Supervisory control system – nearly 90 % of the buildings.
- Daylighting - employed in over 90 % of the buildings. This included controlling electric lighting through dimming or step relay controls and often occupancy control.
- Increased ventilation –over 50 % of the buildings.
- Natural ventilation –almost 40 % of the buildings.
- Heat recovery –about 30 % of the buildings.
- PV systems – about 30 % of the buildings.

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- Advanced glazing systems – about 25 % of the buildings, and the most often mentioned shell element.
- Underfloor air distribution and displacement ventilation – about 20 % of the buildings.
- Ground source heat pumps – about 20 % of the buildings.
- High efficiency equipment for the mechanical systems, with variable frequency drives - about 15 % of the buildings. (This number is probably significantly under-reported since information on this aspect was not requested.)

The overall conclusion from an examination of these high performance buildings is that it is possible to achieve an approach to net zero energy use using technology currently available. However, it is not easy. It requires an integrated design approach together with the incorporation of many modern energy reduction techniques. The importance of the Integrated Design method and its implementation is discussed in detail later in this report.

MEASURES TO ACHIEVE SIGNIFICANT ENERGY SAVINGS

Based on the information obtained from the literature, the Scoping Committee identified a number of measures and approaches that have the potential to achieve a goal of Net Zero Energy Use. Two reports prepared for DOE were helpful in providing direction on the selection of measures (Appendix 4). In these reports, HVAC and illumination energy use were evaluated and systems in which significant improvements were possible were identified. The recommendation is to develop technologies that would:

- Reduce parasitic power requirements
- Provide for separate treatment of ventilation and internal thermal loads
- Improve delivery of conditioning to where it is needed
- Improve part load performance of HVAC components
- Improve the illumination systems.

The specific measures identified by the Scoping Committee are described below and a brief summary of the potential for each measure is given in the following sections. Many of the measures are packages of technologies, systems, and controls that require different design, construction, commissioning, and operations compared to more conventional systems. The measures are not equally applicable in all climates and for all building types. The measures identified by the committee are:

Envelope and Lighting Measures

Insulation

The reduction of heat gain and loss through the building envelope is a relatively simple but very effective measure for lowering energy use. The primary avenues of envelope heat loss and gain are through the roof, walls, floors, doors, and windows of buildings. *The Advanced Energy Design Guide for Small Office Buildings*, ASHRAE, 2004, presents a large number of “Good Design Practice” recommendations in Chapter 4. The specific recommendations for insulation thickness levels depend on climate, and are given in the tables for each of the eight Climate Zones in Chapter 3. The following material is a brief summary of these practices that relate to the opaque components. The recommendations from the Scoping Committee on windows are covered in the next section on fenestration.

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Roofs: Sections EN2 through EN5 describe construction methods to reduce heat loss in roofs and decks made of metal, wood, and concrete. There are two essential concepts. The first is to install continuous insulation over the structure. The second concept is to pay attention to and eliminate all “thermal bridging,” which occurs when a high conductivity member (e.g. a metal purlin, or beam, that supports the roof structure) connects the interior and exterior surfaces. Techniques are discussed how to reduce the effect of thermal bridging for each of the roof constructions.

Walls: Sections EN6 through EN10 describe methods for sufficiently insulating walls made of concrete, wood, and metal, both above and below grade. In multistory buildings, walls may constitute up to 80 % of the exposed surface area of a building and insulation measures are essential. As with roofs, it is essential to provide continuous insulation and to avoid thermal bridges. For “mass walls” (walls made of materials with high thermal capacitance), it is recommended that insulation be placed on the outside of the walls. This allows storage and release of thermal gains generated inside the building and reduces heating and cooling loads.

Floors: Sections EN11 through EN14 cover both internal floors and slab-on-grade floors. As with the other envelope components, continuous insulation and prevention of thermal bridging are essential. Floors support the interior equipment and are often also the upper surface of spaces through which heating and cooling ducts pass. It is recommended that the upper surface of the floor be insulated, which requires special treatment because office and other heavy equipment are placed on the floors. Insulating slab-on-grade floors requires attention to the frost-line in cold climates and insect problems in hot ones.

Doors: Sections EN15 and EN16 give recommended U-values (thermal conductance values) for swinging, roll-up, and sliding doors.

The design goals for the envelope components are durability, indoor environmental quality, and energy conservation. The need to achieve these goals and avoid problems of accelerated deterioration, reduced thermal performance and moisture are discussed in sections EN17 through EN20.

Fenestration

Fenestration performance has a significant impact on most commercial buildings as windows and skylights are essential architectural design elements. Fenestration decisions determine the view and connection with the outdoors for the occupants. Unlike most conventional buildings envelope components, fenestration can become an energy supplier through utilization of solar gain when the building is in a heating mode and through use of daylight year round to displace electric lighting. The specific impacts depend on the fenestration system details; the building type, location and operation; and occupant factors.

Fenestration was historically the thermally weakest link in the building envelope. The thermal conductance was 10 to 20 times higher than insulated opaque building envelope assemblies and the relative cooling impacts per unit area from direct sunlight were even higher. Peak heating and cooling loads from fenestration were a major component in sizing HVAC systems (primary cooling equipment and thermal distribution systems), at times resulting in oversized systems that operate inefficiently at part load for much of the year. The impact of fenestration on annual heating and cooling energy consumption was significant.

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During the last 20 years there have been significant changes in the technology available for high performance fenestration and associated improvements in fenestration energy performance. The three engineering parameters that drive fenestration energy use are conductance (U factor), solar heat gain coefficient (SHGC), and air leakage. Thermal loss has been reduced with mandatory standards that typically require maximum allowable U value, maximum allowable SHGC, and, in some situations, constraints on glazing area.

Thermal Conductance: Low U values are desirable to reduce heating and cooling loads and energy use in severe climates and to improve thermal comfort adjacent to the window. The overall U values are reduced by improving glazing and frame conductance, and to a lesser extent the spacer bars that separate glazing layers. For larger window elements the thermal properties of the glazed portion dominate the overall values while the framing is more important for smaller windows. The National Fenestration Rating Council (NFRC) has developed a procedure for rating the overall U-value for window systems that accounts for all of the construction details (See www.NFRC.org). These ratings account for all of the window system construction and materials details. Typical values can be found in tables in the ASHRAE Handbook and the properties of virtually any window system can be calculated using widely available software tools that are used by NFRC to determine the rated values (e.g. WINDOW 5).

Double pane windows have replaced single pane windows and further thermal improvements include the use of low-E coatings on the inside of the panes and an argon gas fill. Three or even four glazing layers provide additional benefits but these are not yet common, even in very cold climates. The additional layers may be thin plastic layers to reduce weight. The combination of a double glazed unit with low-E coating will produce a glass U-value of about 0.33 Btu/hr-ft²-F and the addition of a gas fill will lower the value to about 0.25 Btu/hr-ft²-F. Typical metal frames without thermal breaks will increase the overall conductance to values in the range of 0.35 – 0.5 depending on window size. Low U values reduce condensation and improve thermal comfort adjacent to the window. State of the art windows and frames have effective assembly U-values as low as some insulated walls. High performance windows can reduce the size of perimeter heating and cooling equipment and even eliminate it in some cases. Furthermore the energy and comfort needs of a perimeter space with a fenestration system with low to modest heat transfer may be low enough to allow a number of different HVAC system solutions that could not be utilized if the loads were high. In addition to energy efficiency, multi-layer fenestration reduces transmission of sound from outside to inside.

Solar Heat Gain Coefficient: Because most commercial buildings have significant cooling loads, lowering the solar heat gain will improve energy efficiency. Conventional clear and bronze glass has an SHGC in the range of 0.6 - 0.8, which results in a very high heat gain from the windows. The best highly reflective glass will reduce SHGC to 0.1, but in most cases this also reduces the light transmission, which makes the space much darker and aesthetically unpleasant to some. Using highly reflective glass to minimize SHGC has fallen out of favor with the renewed interest in daylighting and the visual contact with the outdoors.

The challenge has become to minimize SHGC but to admit adequate enough light to provide effective daylighting in the occupied spaces. Various tinted glasses and modified low-E glasses preferentially transmit daylight but reject near infrared energy from sunlight. These spectrally

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selective glazings can have a visible transmittance (τ_v) in the range of 0.4 to 0.65 and associated SHGC of 0.2-0.3. While the SHGC can be made as low as 0.1 it involves use of darker glass that will not transmit adequate daylight.

Control of Fenestration: An evolving strategy for very low energy buildings is to keep the glass visible transmittance high to capture the benefits of daylight, while providing glare control and solar control via operable shading systems such as shades, drapes, and blinds that can be deployed as needed. Manual systems are cheaper but depend on the occupants to respond appropriately and reliably. Automated systems offer much better and more consistent performance but at greater cost and complexity. In Europe, in contrast to typical US practice, there is widespread use of interior and exterior operable shading devices that work effectively. Dynamic glazings, whose optical properties can be electronically changed in minutes by a factor of 10, are becoming commercially available. They are very expensive today but their costs are expected to drop over time. External shading devices (fixed and operable) are the most effective strategy for reducing solar loads in summer. When properly designed and operated, they allow increased passive solar heating in winter in northern climates and admit daylight while controlling glare.

Air Leakage: In most commercial buildings, air leakage is minimized to reduce loads and improve comfort. However, operable windows that provide natural ventilation in swing seasons reduce the load on the HVAC system. The design of effective naturally ventilated “mixed mode” buildings requires significant expertise in design and operations. A key challenge is to develop control sequences and realistic actuation strategies that provide the benefits without conflicting with operation of the HVAC system.

Design Strategies: In a given climate the combination of glazing area and orientation has a major impact on building energy use. The conceptual strategy for a glazing and façade system that contributes to significant energy reduction could follow two different pathways. In the first, window size and orientation are part of the full design optimization, with simulation tools used to optimize area and orientation and to select glazing properties. Glare control would be handled with manual shades and blinds. The alternative pathway taken increasingly frequently by architects today is to explore design solutions that incorporate large amounts of high transmission glass (e.g. a fully glazed façade). It is important to distinguish between the added glazing that contributes directly to improved daylighting energy savings and additional area that may contribute to appearance or view, and that may negate some potential energy savings. For these designs it is essential that the solar gain, daylight and glare be controlled using operable shades and blinds, ideally with a reliable automated system.

The façade should be designed in two conceptual elements. A lower vision element (2.5' – 7' above the finished floor at each level) would be optimized for view and connection with the outdoors, providing some daylight in the vicinity of the window. This would be complemented with a higher daylight glazing (7' – 10' above the finished floor) whose purpose is to introduce daylight deeper into the space without glare. This approach, with sensible use of glass area and transmittance is most likely to provide performance levels that contribute to large savings. The impact of these façade choices on electric lighting needs is discussed in more detail in the daylighting section.

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Although fenestration systems do not consume energy directly, they do influence overall building energy use in many ways. If the building façade is not carefully designed it may be impossible to meet overall building requirements. Technology is available today, although in some cases it is still costly, to significantly reduce fenestration loads when needed, and to capture beneficial solar gain and daylight. The exact level of energy savings depends on the building type, function, and climate, with careful design necessary to achieve a net zero energy use goal.

Lighting

Lighting can use as much as 40% of the electric energy in a building (USDOE, 2002). However, the design and application of lighting inside buildings can reflect a sophisticated understanding of technologies and human factors with standards set by the IESNA rather than ASHRAE.

Significant lighting energy savings can be achieved by addressing both lighting technology and illumination system design. Properly designed and implemented, it is possible to significantly reduce both the connected electric lighting load and the lighting energy use. A summary of the technology is given in this section and an expansion on the ideas presented here along with additional detail on these illumination measures is given in Appendix 5.

There are four important areas in which illumination technology and design can produce reductions in energy use. These are:

1. Low levels of general illumination with task and accent lighting added to locations where higher light levels are required. This may require re-evaluation of lighting recommendations for general illumination.
2. Daylight offers significant potential energy savings. However, sensing and control systems need to become more robust and less expensive before these savings can be realized, particularly for sidelighting (i.e. windows).
3. Motion (occupant) sensors should be widely implemented. These are a robust technology that can be implemented without significant expense.
4. The use of the most efficient sources and fixtures, consistent with the design considerations and human factors requirements, for task and ambient lighting.

Approaches to address these four areas are discussed in the following:

Brightness based lighting recommendations: Current light level recommendations are based upon long-standing, assumptions about the visual system (CIE, 1932). However, they do not properly represent brightness perception (e.g., Alman, 1977). The use of a perceived brightness measure would require different lighting levels for ambient and task lighting. Ambient lighting levels could be reduced significantly without compromising safety. In general, visual performance increases as light levels increase, but at an ever diminishing rate (Rea and Ouellette, 1991). Over the past 35 years recommended light levels have been cut by half or two-thirds without apparent loss in worker productivity. However, reducing light levels *will* strongly reduce visual performance for very small or low contrast tasks. Therefore high light levels need to be maintained in critical task areas (e.g., surgery) or where the visual task is inherently difficult to see (e.g., repairing watches).

Even though task lighting levels could be reduced below current recommendations without seriously affecting visual performance, there is probably little reason to do so in areas where visual tasks are commonly performed. If the illumination system delivers illumination only to the task

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area, high light levels can be maintained without significant impact on the electrical load because visual task areas are small relative to the entire building space.

Application efficacy: Luminous efficacy (lm/W) is often used to compare lighting systems as it is assumed that those lighting systems that produce greater lumens per watt are more “energy efficient.” This is generally true for lighting systems that emit diffuse, ambient light throughout an architectural space (e.g., direct/indirect suspended fluorescent lighting systems for general lighting), but it is *not* true for directional light sources (e.g., track halogen lighting for illuminating a picture on the wall). Application efficacy (Rea and Bullough, 2001) is based upon the notion that the most efficient lighting system is one that delivers light to the desired location and *only* to that location at the lowest electrical power. Task lighting with high application efficacy combined with reduced ambient lighting levels will lead to lower power densities, and thus, lower energy use.

Lighting controls: Lighting controls have the potential to reduce connected load by large percentages without negatively impacting performance (Lighting Research Center, 2004a; ; Jennings et al., 2000). Motion sensors can be used throughout a building, and offer a practical solution to effectively reduce lighting energy in unoccupied zones in buildings. Photosensors on the other hand represent a much smaller potential in areas with illumination supplemented by side lighting (i.e., windows) due to limited access to daylight (often less than 20% of the floor space), higher initial cost for installation and commissioning, and higher costs and lower reliability when used in conjunction with fluorescent dimming systems.

Motion sensors: Illuminating architectural spaces when they are unoccupied is almost always a waste of lighting energy, unless security is an issue. It is important to be able turn lights off in unoccupied spaces. Motion sensor technologies are inexpensive, widely available, simple to install, and perform well in applications (Lighting Research Center, 2004a). Currently, they are widely used in new construction, but not in existing buildings. Wide spread usage of motion sensors could reduce lighting energy use by as much as 30%.

Photosensors: Photosensors that control the operation of electric lighting systems in response to daylight have been under development for 25 years, but are still not a robust technology. They work best with skylights because daylight and electric lights in the ceiling produce nearly the same spatial distribution of light within the space. Photosensors can readily be used to substitute daylight from skylights with electric lighting, but are difficult to commission when used in conjunction with side lighting (i.e., windows). The biggest challenge to overcome is establishing a functional relationship for substituting electric light from the ceiling with daylight from windows without sudden changes in illumination (Rubinstein, 1989). Recent self-commissioning laboratory prototypes have been developed and shown to work quite well in a few demonstration projects, yielding 50% energy savings in daylit spaces (Lighting Research Center, 2004b). On average, daylight can probably be effective for 40% the floor space in buildings, significantly reducing daytime electric lighting load.

Photosensors are often closely associated with dimming rather than switching on and off, fluorescent lighting systems. Dimming systems can cost 3 to 10 times more than switching systems. Frequent switching in response to daylight has been found to cause annoyance among occupants (e.g. Boyce, 1984), whereas infrequent switching and switching only after high daylight

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levels are present mitigates complaints but reduces energy savings. Photosensors have a good, but presently unrealized, potential for energy savings.

Expected energy savings from improved lighting systems: Estimated electricity reductions from the different lighting measures are given below:

Task/Ambient lighting: up to 20 %

Lighting Controls:

Motion (occupancy) sensors: up to 30 %

Photosensors (with daylighting): up to 20 %

Significant lighting energy reductions are possible, but are very dependent on building type, occupancy patterns and climate.

Integration of daylighting with high efficiency lighting

Daylighting is one of the primary integrated architectural design strategies used to improve the energy efficiency of commercial buildings. It has a direct impact on commercial building energy use by reducing energy use for lighting, and an indirect impact on the building thermal loads through increased fenestration loads and decreased electric lighting loads. Some of the design ideas associated with daylighting are discussed in Appendix 5 and resource materials are given in the References.

Since electric lighting is typically 25-40% of a buildings source energy use, strategies that reduce electric lighting energy use are critical to achieving a significant energy reduction goal. Extensive simulation and modeling and more limited field testing suggests that a well designed daylighting system can displace at least 50% of electric lighting needs and can have a neutral or positive net impact on thermal loads. The obstacles to achieving this impact routinely are three fold: 1) availability of cost effective technology and systems that “work”; 2) availability of design expertise to successfully design and optimize systems for building specific applications; 3) successful installation, commissioning and operations. Although the technologies have been successfully deployed on a limited basis by early adopters and are increasingly being specified as part of many “highly efficient” buildings, extensive measured performance of these buildings is lacking.

The overall impact of daylighting on building energy use depends on four factors:

1. the fraction of the building floor area that is impacted
2. the fraction of the working hours per year that electric lighting is reduced
3. the fraction of the illumination requirement met by daylight
4. the thermal impacts of the fenestration design and operation, and the effects of reduction in electric lighting energy use on building heating and cooling loads.

Daylighting systems require a relatively high degree of engineering design and integration with the electric illumination system. They must be properly installed and commissioned to operate effectively. The costs of some of the key elements are currently too high for many owners to justify today on a traditional payback basis. These systems today require a relatively high degree of engineering design and systems integration, more typical of leading edge firms or larger projects that employ extensive design teams and consultants. They also require more follow-through to construction, commissioning and operations to ensure that the control systems are working well.

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Integration of controls based on use of dimming ballasts requires that the proper combinations of ballast, lamp and fixture are employed to ensure good performance and avoid potential problems with premature lamp failure. Current costs of some of the key elements, such as dimming ballasts, are too high for many owners to justify today on a traditional payback basis. Controls using photocells must be calibrated and proper design and installation is needed to ensure that the daylight responsive system dims or turns off the lights as needed. Overall these projects are more complex and more costly than conventional non-dimming systems without photocell control. It is anticipated that the current interest, growing experience, and market volume will lead to improved, lower cost systems.

Significant reductions in lighting energy use through use of daylighting in combination with control of the electric lighting systems will alter the thermal balance in buildings. Typical lighting levels are a major component of the internal air-conditioning load. In general, reducing electric energy for lighting system will reduce cooling loads and increase heating loads, while reducing peak electrical demand.

HVAC Distribution Systems

Parasitics losses

Parasitics losses in HVAC systems stem from several sources. Although individually many of these losses are small, they can combine to represent a significant use of energy. Various HVAC system losses are identified and discussed below.

Duct static pressure: The static pressure for air distribution systems for commercial unitary HVAC equipment is typically in the range of 1" water or higher. A relatively high static pressure combined with a large number of blower operating hours in a commercial application can lead to significant annual energy use. Minimizing the system static pressure requirement probably represents the largest potential energy savings for an HVAC system, especially for a commercial application that may be operating continuously.

Although it will add to the size and cost of the ductwork, it is recommended that the design static pressure be lowered to 0.5" water for packaged systems. This recommendation is based on a review of data for commercially available unitary HVAC packaged rooftop equipment that indicates an approximate 25% reduction in blower power at the lower static pressure. For a blower that operates only during the cooling season, the blower power reduction for a typical building would translate into an approximate 5% reduction in overall cooling energy usage. The savings would increase to 15% if the blower operates continuously. In larger commercial building with more extensive high-velocity duct systems, the overall system static pressure drop can be in excess of 6" water, and greater savings are possible. Metrics need to be formulated for larger systems, and specifically VAV systems.

Duct Leakage: Indoor air ductwork should be sealed to the greatest extent practical. Any leakage of conditioned air from the supply duct into an unconditioned space or into the wrong conditioned space is a loss of energy. Likewise, a leak of unconditioned air into the return duct will create an additional load on the cooling/heating coil. Further, air leakage into or out of an unconditioned space may cause an imbalance in the internal building pressure and create unplanned infiltration/exfiltration. Even leaks within the conditioned space may cause unplanned air flow between conditioned spaces, which results in lost energy if the result is an over or under

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conditioning of a given space. Duct leakage has a significant impact on energy use. Commercial duct leakage has been measured at 10 to 20% (Fisk et al. 2000), and a 15% duct leakage can lead to a fan power increase of about 25 to 35% (Diamond et al. 2003).

Duct Heat Transfer: Heat transfer to and from indoor air ductwork should be minimized by maximizing ductwork insulation and/or not locating ductwork in unconditioned space. Inadequate duct insulation will lead to excessive heat transfer between the ductwork and unconditioned or conditioned spaces, representing a loss of energy and/or the creation of additional load on the cooling/heating coil.

Indoor Air Blower Operation: Indoor air blowers should be shut off when ever air flow is not needed. Further, variable speed or multi-staged drives should be selected so that the air flow and fan energy use can be reduced during periods of reduced load. In many cases, the indoor air blower is required to introduce outdoor air for ventilation and energy is then wasted by unnecessarily recirculating large amounts of room air.

Condenser Air Fan Operation: Condenser air fans should never remain running when the rest of the system is off. Variable speed or multi-staged drives should be selected to modulate the flow in response to reduced system load.

Refrigerant Piping: Field built up, or split system, refrigeration equipment should have the refrigerant line sizing and installation practice carefully reviewed. The pressure drop in the refrigerant lines carrying vapor between the evaporator and compressor and between the compressor and condenser will increase the power requirement of the compressor. Basically, all refrigerant vapor lines should be sized as large in diameter as possible without jeopardizing oil return to the compressor. Refrigerant vapor lines should also utilize long radius elbows, and must have the cutoff burr removed from the ends of all tubes.

Water Piping: The pumping power in water circulation systems can be reduced by increasing pipe diameter and minimizing pressure losses in fittings. Control valves should be carefully selected. Even when wide open, the pressure drop through a control valve is typically equal to that of the component it controls.

Water Circulating Pumps: High efficiency circulating pumps and motors should be used. Pumps should never remain on if the circulating loop can be shut down. In addition, variable speed pumps represent an opportunity to save significant energy in applications in which the flow rate can be lowered in response to reduced thermal load.

Distribution System Controls: While variable-flow air and water circulation systems offer significant energy savings over conventional constant-flow systems, savings are maximized only when flow control is integrated between fans and dampers (or pumps and valves). For example, conventional VAV control systems modulate dampers to control flow at the zone and adjust fan speed to maintain a duct pressure setpoint. This independent control often results in all dampers partially closed while the fan maintains an unnecessarily high pressure setpoint. Integrated flow control would ensure that the duct pressure is no higher than necessary to maintain at least one damper fully open. In larger commercial buildings with central cooling plants and distributed air

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handlers, significant savings in fan and pump power can often be achieved by optimal selection of water and air setpoints (ASHRAE 2003).

Electrical Standby Power: Electrical standby power for HVAC components is probably the smallest of the parasitic losses, and perhaps is limited to ensuring that crankcase heaters are not energized while compressors are operating, that water freeze protection heaters are not energized unnecessarily, and that electric control valves, relays, and actuators are not energized while the rest of the system is off.

Ventilation

The conditioning of ventilation air represents a major energy requirement in many commercial buildings. The impact is dictated by building type and climate. The building type and its occupant density determine the required ventilation rate, which can range from 0.14 cfm/ft² (e.g., hotel rooms, office space) to more than 2.0 cfm/ft² (e.g., cafeterias, auditoriums). Outdoor air conditions determine the heating and cooling loads, both sensible and latent, imposed by the ventilation. Depending on location, Figure 3 shows that these annual loads can range from insignificant to as great as 100,000 Btu/cfm, or as much as 200,000 Btu/ft² (Brandemuehl, 1999).

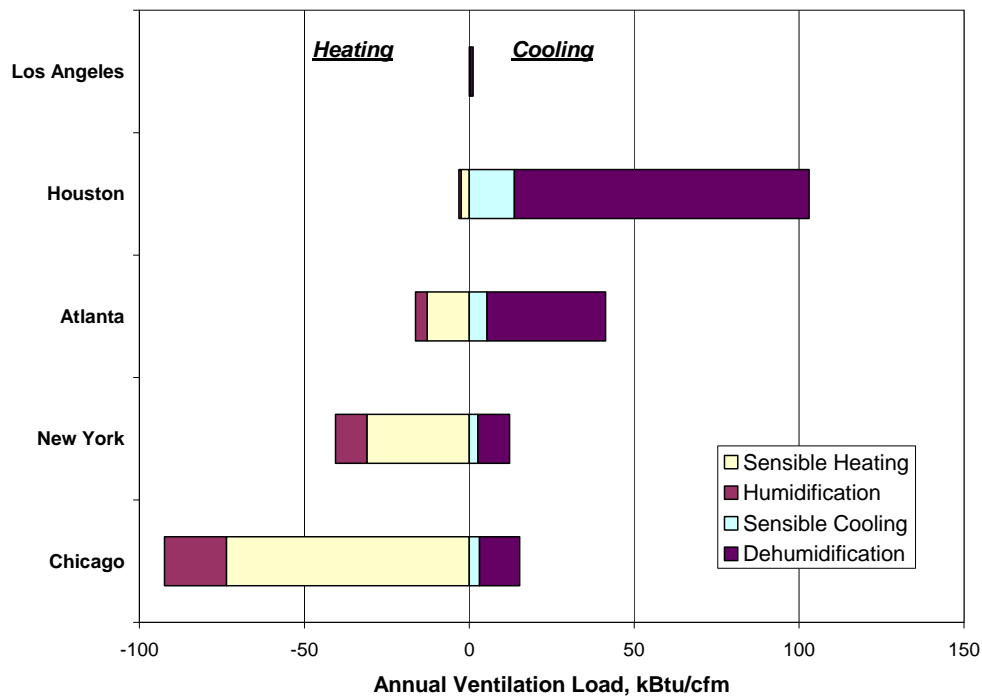


Figure 1. Annual Ventilation Sensible and Latent Loads for Several U.S. Cities

In the conventional forced or mechanical ventilation system, blowers are used to bring in outside air through a dedicated ductwork system or through the heating/cooling system unit via an outdoor air damper or economizer. This outdoor ventilation flow then mixes with the return air. A single coil is then used to either cool and dehumidify or heat the mixed flow, which then becomes the supply air stream for the building.

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Today, many options to the conventional system are available. The selection, design, and control of a ventilation system to maximize energy efficiency depend on geographic location, building design and use, and the selection of the base heating/ cooling equipment. Major reductions in energy use can occur through the use of:

- economizers,
- separate processing of the ventilation air, and
- energy recovery from the exhaust stream.

The crucial issue is to reduce the energy consumption required to process the ventilation air to provide adequate indoor air quality while at the same time maintaining the desired temperature and humidity levels in the building space.

Economizer: An outdoor air economizer allows the use of cooler outdoor air, when appropriate, to meet building cooling load and reduce energy consumption of compressors and chillers. The required equipment include a larger outdoor air damper to allow up to 100% outdoor air and the instrumentation and controls to determine whether the outdoor air is “cool enough” to provide cooling. Controls are typically based on measurements of air temperature or enthalpy. ASHRAE Standard 90.1-2004 requires the use of economizers in all but the warmest and most humid US climates.

Separate processing of ventilation air: Systems in which the ventilation air is processed separately from the return air provide the opportunity to reduce energy use and maintain accurate humidity and temperature control. As commonly employed, one coil is used to cool and dehumidify the incoming ventilation air stream and a second coil is used to cool the return air stream. The two streams are then mixed and distributed to the spaces.

Humidity control requires low source temperatures (40 to 50°F) to condense moisture from the ventilation air, and thereby to control dew point temperature in the space. Sensible cooling can be achieved with relatively high cooling source temperatures (as high as 65°F) if the thermal coupling between the transfer fluid and the space is sufficiently great. This freedom in cooling source temperature can maximize natural free cooling, while maintaining acceptably high temperature differentials for the heat transfer fluid to minimize transport energy. Provision of lower temperature cooling for dehumidification can then be linked only to the necessity for dehumidification as determined by outside air dew point temperature.

The ventilation air is dehumidified to a level so that the mixed supply stream is at the desired supply humidity level, and the return stream is cooled, as necessary, so that the desired supply temperature is obtained. Reheat is eliminated and the coil in the return stream provides only sensible cooling. The sensible-only cooling coil can be supplied with cooling from a higher temperature source, operating at a higher COP.

A system that separates the ventilation and dehumidification function from the sensible conditioning function is known as a Dual Path System or a Dedicated Outdoor Air System (DOAS). The separation allows for the optimization of both design and operation of each of the two separate functions, leading to optimal efficiency of both heat transport and provision of cooling. In the simplest cases, both functions can be included in a single rooftop unit or air handler and utilize a single supply fan. In larger systems, dedicated air handlers and separate ductwork can be provided for each function.

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The performance of these systems and their potential for energy savings has been documented in the HVAC literature (Mumma and Jeong 2005, Khattar and Brandemuehl 2002, Stanke 2005, Morris 2003). Recently, these systems have also been coupled with radiant cooling systems (Jeong et al. 2003).

Energy recovery from the exhaust stream: The exhaust stream represents a potential source of energy for conditioning the ventilation air (Niu and Zhang 2002, Roulet et al. 2001). In summer conditions the exhaust stream is cooler and drier relative to the ambient air, and in winter it is warmer and more humid than the cold and dry outdoor air. Devices have been developed to transfer heat and moisture from the exhaust to the ventilation air.

A heat recovery heat exchanger exchanges heat between the incoming outdoor air and the building exhaust air. In the summer the outdoor air would be cooled before entering the building and in the winter it would be warmed. A sophisticated damper arrangement is needed to obtain free cooling (the economizer) when the outdoor air temperature is below the exhaust air temperature or to bypass the heat exchanger under selected conditions.

The five common methods for providing the heat recovery to reduce the energy impact of ventilation:

- Rotary heat exchanger. Heat is transferred between the two air streams by alternately passing a heat absorbing matrix material through each stream. The system requires the two air streams to be passing parallel to each other and there is a potential for leakage and carryover between the two streams.
- Crossflow air-to-air heat exchanger. Heat is directly transferred through a membrane that separates the two air streams that flow perpendicular to each other. There is no cross-contamination of two streams.
- Heat pipe heat exchanger. Heat is transferred between the two streams by a device that alternately evaporates and condenses an intermediate two-phase fluid using gravitational forces. In the simplest installations, the heat pipe transfers heat in only one direction and can not be used to reduce ventilation loads in both winter and summer.
- Indirect heat transfer loop. A liquid heat transfer fluid, usually a brine, transfers heat between the two air streams. The brine loop is comprised of two air-to-liquid heat exchangers, a pump, and connecting piping. The main advantage of this approach is that the exhaust and outdoor air streams do not need to be adjacent to each other.
- Air-to-air heat pump. The configuration is similar to the indirect heat transfer loop, except that a heat pump is used. This can effectively transfer heat when the temperature differences between the ventilation and exhaust streams are small or even negative.

Energy recovery devices operate similarly to the heat recovery devices, but are able to transfer both latent and sensible heat, thus recovering energy on a total enthalpy basis. As with the heat recovery heat exchanger, free cooling can not be obtained when the outdoor air enthalpy is below the exhaust air enthalpy unless the control strategy allows the enthalpy exchanger to be bypassed under these conditions.

Energy recovery devices are constructed in two configurations: a rotary heat and mass exchanger that uses a desiccant material on a substrate matrix and a crossflow heat and mass exchanger that

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uses a water-permeable membrane. The physical difference between the heat and energy recovery exchangers is the construction material of the matrix and membrane. Energy recovery devices require the ventilation and exhaust air streams to be in close proximity.

A variety of commercial products are also available for reclaiming heat and/or moisture from the exhaust stream. These include an energy recovery heat pump, an air conditioner with reheat from refrigerant subcooling, and an air conditioner or heat pump with reheat from refrigerant hot gas (see references).

Depending on building type and climate, ventilation energy recovery can offer a major opportunity for building energy reduction, especially for buildings with high occupancy in either cold climates or in hot and humid climates. The opportunities are often tempered by parasitic power needs and the conflict with other energy-saving opportunities. All system implementations impose greater fan and/or pumping power. If the designer is not careful, the additional energy consumption can overshadow ventilation energy savings. The energy recovery systems will also often compete with air economizer systems that seek to introduce outdoor air for free cooling.

The most fundamental limitation of the heat recovery approach is the requirement of a central exhaust air stream. Furthermore, the effectiveness of the heat recovery system can be limited by the fact that the exhaust airflow rate is often significantly smaller than the outdoor airflow rate due to building pressurization and local exhaust.

Demand Controlled Ventilation: The most effective energy saving strategies eliminate loads before they occur. Demand controlled ventilation (DCV) systems seek to reduce ventilation energy use by limiting the ventilation airflow rates to the minimum required for adequate indoor air quality. Building energy costs are reduced by minimizing the amount of air to be conditioned. The challenge for such systems is accurate characterization of ventilation demand. The most common approach involves measurement of CO₂ concentration either in the return ductwork or in selected occupied spaces. Since occupants represent the dominant CO₂ source in buildings, the CO₂ concentration level relative to that in the outside air serves as a surrogate for occupancy level.

The HVAC literature includes many analyses of DCV energy savings and case studies of installed system performance (Brandemuehl and Braun 1999, Krarti and Al-Alawi 2004, Mercer and Braun 2005, and Taylor 2006). While the opportunities for energy savings are intuitive, care must be taken to ensure sensor reliability, representative CO₂ measurements, and proper integration with economizer controls.

Natural Ventilation

Natural ventilation uses a building's form, organization, and openings, in conjunction with wind and warm air buoyancy, to supply air to occupants and remove heat from occupants and the building (G.Z. Brown et al, Natural Ventilation in Northwest Buildings, 2004). Natural ventilation strategies can provide all or most of the ventilation and cooling in appropriate climates.

Natural ventilation can both reduce operating costs by decreasing the need to mechanically ventilate and cool, and reduce construction costs by reducing or eliminating cooling equipment. Where complete mechanical systems are required for an entire building, natural ventilation may be redundant and not cost-effective.

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Natural ventilation can be used to supply outside air to occupants, to reduce pollutants produced by internal sources, to improve personal cooling by increasing heat loss from the skin due to evaporation/convection, and to remove heat stored in the building mass during the night, so that the mass can cool the space the following day.

Successful natural ventilation strategies need to meet a number of challenges, and design strategies need to be crafted by a team that includes the owner, users, architects and engineers. The design should consider occupant comfort criteria, micro-climate conditions, possible acoustic problems, outside air pollutants, and minimization of building loads.

Distribution of heating and cooling to spaces

The energy consumed by fluid transport (fans and pumps) in a typical air distribution system is normally about 15 % of the HVAC energy use. Transport energy includes energy for pumps and fans, including cooling tower or condenser fans. The common methods of reducing transport energy include significant decreases in pressure drop along thermal transfer conduits and increased temperature differentials of the heat transfer fluid, which can provide only incremental reductions in transport energy use.

Conventional air conditioning design in climates that require dehumidification is driven by the need to provide conditioned air with a 55° F dew point temperature. The required temperature of chilled water or refrigerant in cooling coils must then be between 40° and 45° F.

One strategy to reducing transport energy when air is the medium has been to cool the air to below 50° F using low temperature chilled water (below 40° F), which decreases the flow rate of the air and water streams. This strategy directly reduces the potential for natural free cooling. The reduced chilled water temperature significantly decreases the availability of waterside economizer cooling, while reduction in supply air temperature decreases the effectiveness of both air side and water economizer operation.

Another strategy to reduce transport energy in air conditioning is to use water to provide sensible cooling with ventilation and dehumidification provided by supply air. Because of the higher specific heat of water and the greater efficiency of liquid circulation systems, the transport energy for a given amount of cooling conveyed with water is less than that with air. Estimates of the difference in the transport energy requirements for water compared to air range from one-half to one-tenth for the same amount of cooling. The estimates of savings vary with the application depending upon whether the air flow provides dehumidification, the equipment used to couple the water stream to the space, and the water temperature differential. The energy involved in fluid transport should be thoroughly evaluated before recommendations are made in the Guides.

Because the heat capacity of water is greater than that of air, the flow area for water pipes is much smaller than that for ductwork to carry the same amount of energy. A water based distribution of heating and cooling energy may decrease the building volume required for HVAC services substantially, even when a DOAS is needed for the ventilation air.

Heat transport issues in the heating mode are primarily concerned with uniform provision of heat to the space. A high supply temperature of the heat transfer fluid may not significantly impact boiler

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or furnace efficiency and can dramatically reduce the transport energy. However, in heat pump systems a high temperature will lower COP significantly. High temperatures can complicate the transfer of the heat to the space and careful design is needed.

Alternatively, a better strategy may be the use of condensing boilers and “outdoor reset” or equivalent control strategies to reduce the temperature of the circulating water/brine to the lowest temperature that will meet needs. Measured savings of about 50% relative to conventional hot water systems (180°F) have been demonstrated for schools (Durkin, ASHRAE Journal July, 2006). If the thermal coupling between the space and heat transport system is sufficiently high, as with radiant floors or panels, higher rates of heat transfer can be achieved even with a lower supply temperature. Space conditioning with a lower temperature heating source furthermore lessens the possibility of local temperature extremes within spaces.

Achieving a 50% reduction of energy consumption in a building requires a reduction in transport energy. In conventional systems it is difficult to reduce transport energy significantly by lowering the temperature differences. Lower temperatures result in reduced potential for free cooling (economizers). Using water rather than air to distribute energy to the space has the potential to reduce transport energy, but will require a careful design and an assessment of the tradeoffs.

Thermal Storage

Most electric utilities have developed rate structures in which the price of electricity depends on the time of use. A significant differential between the daytime and nighttime electric rates provides an incentive to shift operation of the cooling equipment to off-peak periods. Although the energy use may be reduced somewhat, the main advantage is the shift in electrical demand and reduction of the cost of air conditioning.

A thermal storage system uses the combination of a conventional electrically-driven cooling unit and a thermal store to meet the cooling requirements of a building. The two media commonly used in thermal storage systems are chilled water and ice. Charging the store, which means either chilling or freezing water contained in large tanks, is performed with cooling equipment designed to operate at lower temperatures than conventional air-conditioning units. The fluid circuit is more complicated than that of a conventional system to allow the coolant to flow through the chiller, the store, or the cooling coil depending on the control mode. The mass of the building can also be used as a thermal store.

The two basic control strategies used in thermal storage systems affect both the capacity of the components and the cost of operation. In a full storage strategy the storage provides all of the cooling during the on-peak period. The chiller operates only during the off-peak period to charge the store. In the partial storage strategy the store and the chiller are used simultaneously to meet the building load. During the on-peak period, the coolant flows first through the chiller where it is cooled to an intermediate temperature and then it enters the store where it is cooled further before going to the coil. During the off-peak period, the tank is charged by coolant flowing through the evaporator of the chiller. The installed capacity for the partial storage system is less than for the full storage system because the chiller operates on both on- and off-peak. Thus the equipment is smaller and the installation costs are less.

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The operating costs of thermal storage systems are less than those of conventional air conditioners but the energy use is typically higher. The evaporator temperature required for ice or cold water systems is lower than for conventional systems, and the resulting COP is lower. There is additional pumping power required as the piping network is more complex. However, at night the ambient temperatures are lower than in daytime, and the COP is increased due to the lower condenser temperature. This may somewhat compensate for the lower COP required to produce ice. Finally, if the chiller is designed to operate at full load during the charging cycle, the COP may be higher than if the chiller operates at part load to meet a varying daytime building load.

The capital costs of thermal storage systems are probably higher than conventional systems. The reduced capacity of the chiller at the lower evaporator temperature tends to require a larger physical size than a conventional chiller. On the other hand, the installed chiller capacity for a thermal storage systems tends to be less than for a conventional system because while conventional cooling system chillers are sized to meet the design (maximum) building load, thermal storage systems spread out the chiller load on the cooling system over a longer operating period than conventional systems and so the installed chiller capacity is less. Storage tanks are an additional cost and the design configuration and control strategy employed affect the size and cost of this component. In many situations, the savings associated with smaller equipment can more than offset the additional cost of the storage medium.

The building HVAC system can be the same as it would be with a conventional chiller. However, systems designed to use the lower supply air temperature obtainable with the cold store operate with lower supply air flow rates, which reduces fan power and the size of the ducts.

HVAC Primary Systems

Water loop heat pumps

Water loop systems are expected to have capital costs intermediate between roof-mounted unitary systems and central chiller/VAV systems, but offer excellent zone-level temperature control. In addition, they readily accommodate situations in which some zones are calling for heat, while others need air conditioning. In the former heat is extracted from the common building loop, while in the latter heat is rejected to the loop, improving efficiency of both sides. When heat exchange between zones is out of balance, which would heat or cool the loop to its set points, an auxiliary heat source (boiler) or sink (cooling tower) operates to restore balance. Unitary water loop heat pumps are generally optimized for a very modest loop temperature range.

Ground Source Heat Pump Systems (GSHPs) for commercial buildings usually employ zone-scale, extended temperature range, unitary brine-to-air heat pumps on multi-zone loops or a common building loop, similar to water loop heat pumps. GSHPs use the ground, ground-water, or even alternatives such as treated sewage discharge as the heat source and sink. In general, commercial systems are divided into closed or open systems. Closed loop systems are ground coupled, and circulate brine through heat exchangers buried in the ground, or sunk in a body of water. Open systems typically use ground water drawn from an aquifer for heat exchange, and usually return it to the ground. Typical “hybrid” systems include a closed circuit fluid cooler to augment the ground heat exchanger, since larger buildings tend to reject more heat than they recover on an annual basis. Typical installations include centralized dedicated outdoor air systems (DOAS) for ventilation, particularly in colder climates.

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The best GSHP designs are also very simple. With a dedicated outdoor air system providing dry ventilation air, there is no condensate at the heat pumps. In addition, temperature is autonomously controlled by zone-level thermostats. Typically, a 2-way valve is installed on most zone pumps, so that water circulates through them only when their thermostats call for compressor operation. Differential pressure at the far end of the system controls a variable speed loop circulation pump. The indoor and outdoor circulating systems will then use less than 10% of the HVAC energy. A central control system for setback and other functions may further improve efficiency.

Ground source heat pumps have been successfully used in systems ranging from residential (3- 5 tons) to commercial buildings of more than 1000 tons. Because capital costs are relatively high they are generally not recommended for the mildest climates. In situations in which cooling loads predominate, large enough closed-loop systems may be prohibitively expensive, so hybrid systems (with a closed circuit fluid cooler) are increasingly popular. Cold-climate and moderate-climate school installations have been very successful because the moisture in the ground around the heat exchanger boreholes freezes, resulting in good contact between the tube and earth and improving the heat transfer to the ground. Because the temperature of ground water is generally moderate, open loop systems are less disturbed by load imbalances. Geology and groundwater regulations matter. Problematic areas include locations where a steel casing is required around drill holes and locations with hard igneous and related rocks. Most of the problems with GSHP systems result from design errors, including vertical heat exchangers that are spaced too closely, undersized piping that increases pumping loads, inadequate attention to the benefits of high efficiency heat pumps (rejecting less compressor energy to the ground), and lack of attention to the heat buildup in the ground in cooling-dominated systems.

Nine case studies of buildings with an average floor area of 45,900 ft² were analyzed by Caneta Research. The buildings on average performance used 60 % of the energy that a conventional system would use. The increase in capital cost was about 20 % over that of a conventional system.

Water loop and ground source heat pump systems can have significant reductions in energy and electrical demand. This technology is most appropriate for buildings in climates where heating loads are large and are greater than cooling loads. Although these systems are \$600-\$700 per ton more expensive than packaged air source systems, in situations with large loads the capital costs can be balanced by energy savings and low maintenance costs.

Variable capacity equipment

Variable speed air movers and water pumps and variable capacity compressors are essential components in reducing transport energy. For fans and pumps, variable capacity is generally achieved by variable speed motor drives while for refrigerant compressors there are numerous capacity modulation mechanisms available, including multiple compressors for unitary equipment, and multiple or variable speed chillers for built-up systems. Variable speed and capacity control should be incorporated in low energy HVAC systems.

Frequently, the part-load efficiency for variable capacity equipment will be significantly higher than that for single-speed equipment. Because almost all equipment operation is at less than full load, even for properly-sized systems, there are energy savings. Additionally, there are small power conversion losses in the drive. It is recommended that a mix of base-load fixed-capacity chillers and modulating chillers be employed in multiple-chiller systems.

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With variable speed control of the indoor air blower, the indoor air flow rate is reduced when the thermostat set point is satisfied. By reducing the air flow to half, the blower power will be reduced to at least half, and in ducted applications by as much as three quarters. Utilization of variable speed indoor air blowers is relatively straight forward and can be implemented with fairly simple control algorithms.

Variable speed control provides similar benefits for water pumps. If the flow rate can be cut in half, the pump power can be reduced by up to three quarters. For chiller water loops, the water flow rate can be reduced as the chilled water load drops. Peak flow is only needed for peak load conditions and at low loads the heat exchange may be adequate. However, the control requirements will be more complex and will need to insure that humidity control is not lost and that chillers do not freeze, etc. Similarly for heated water loops, the water temperature and flow rate can be lowered as the heat load is reduced.

Variable capacity provides a significant benefit for refrigerant compressors. The variable capacity may be in the form of a single variable capacity compressor, the staging of multiple fixed capacity compressors, or fixed capacity compressors in combination with a variable capacity compressor. The control algorithm is again fairly straight forward, in that the total compressor capacity is reduced in response to a reduced cooling load. The relatively smaller compressor capacity then operates in conjunction with the fixed size condenser at a reduced condensing pressure and resultant higher efficiency. Similarly, heat pump compressors operating in the heating mode can employ variable capacity.

Variable or two-speed speed control of refrigerant condenser fans, typically in combination with the use of variable capacity compressors is also possible. As the compressor capacity decreases for a fixed condenser system, the compressor power will decrease by an amount greater than the simple capacity decrease. Optimal control algorithms allow the minimum total of compressor and fan power to be selected. The control algorithm is dependent on the specific condenser fan and compressor characteristics. Similarly, variable speed control of cooling tower fans can be integrated into the compressor control.

Optimization techniques allow the best operating combination of compressors, fans and pumps to be determined as a function of load, climate, and equipment characteristics. In optimal control, the system is operated so that the total compressor, fan, and pump power is at a minimum for each operating condition. Algorithms for near-optimal control have been developed that are simpler to implement and provide nearly the same benefits as optimal control.

Evaporative Cooling

Direct evaporative cooling, in which water is added to an outdoor air stream to provide cool supply air, is limited by the wet-bulb temperature of the entering air stream. Direct evaporative cooling is most applicable in geographic regions where the outdoor air wet-bulb temperature is below approximately 70° F for a significant fraction of the cooling season (2004 ASHRAE Handbook of HVAC Systems and Equipment, page 19.1). While evaporative cooling is often used to directly condition building air, it can also be applied to precool the entering air for air-cooled condensers (Yu and Chan 2005).

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In indirect evaporative cooling, water is added to a secondary air stream, which then circulates through a heat exchanger to cool the supply air stream (Costelloe and Finn 2003, Hunn and Peterson 1996, Maheshwari et al. 2001). The indirect evaporative cooling system is more complex in that it adds water to a building exhaust air stream, and then passes that air through a heat exchanger to in turn cool the incoming make up air. The exhaust air would generally have a wet-bulb temperature below 70° F, making indirect evaporative cooling applicable to a wide array of geographic regions. Use of indirect evaporative cooling can either be a stand alone system or be combined with the outdoor air economizer of a mechanical cooling system. Multiple stage direct/indirect systems extend the range in which evaporative cooling can meet the building load.

The power demand and energy use of an evaporative cooler, which is the sum of the air blower and the water pump, may be considerably less than the power demand and energy use of a mechanical refrigeration system. Evaporative systems are particularly advantageous for pre-conditioning outdoor air streams when outside air rates are high. The cost and amount of water used may be significant in some locations, though it is evaporative coolers may use less water than that used for electricity production to operate a chiller.

Incorporating direct evaporative cooling with economizer control extends the range of free cooling to conditions in which the outdoor air stream wet-bulb temperature is below approximately 70° F. Alternatively, an indirect evaporative cooler could be added to the economizer such that water is added to a building exhaust air stream, which is then passed through a heat exchanger to in turn cool the incoming air. By making use of the building exhaust air, which would generally have a wet-bulb temperature below 70° F, evaporative cooling could be considered for wider geographic regions.

Direct evaporative coolers are generally limited in applicability to the dry southwestern regions of the country. Indirect evaporative coolers extend the range of evaporative devices to more humid regions. Evaporative cooling increase water consumption and reduce electrical consumption.

Desiccant dehumidification and cooling

Desiccants are materials that have a high affinity for water vapor. They can be part of a sustainable approach to maintaining healthy and comfortable indoor environments. Desiccants can dry air without first cooling the air below its dewpoint. The latent cooling provided is typically more than twice the sensible cooling. Because they provide 2-4 times greater specific dehumidification than conventional approaches, they can be economically applied to ventilation air, and potentially eliminate overcooling. Once the desiccant is loaded with water, heat is used to return the desiccant to its “dry” state. The high electrical demand of the compressor in a conventional air conditioner is replaced by thermal energy used to regenerate the desiccant. This creates an important opportunity to use high or low grade solar thermal energy or waste heat for air conditioning. Desiccant systems employ either solid or liquid desiccants. Hybrid systems in which the desiccant is combined with mechanical air-conditioners are also becoming available.

Liquid desiccant systems: Historically, in liquid systems both the conditioner and regenerator utilize beds of packing material similar to those in a cooling tower. The desiccant, which is a solution of a salt and water, is first cooled by a refrigeration system and then sprayed onto the bed of the conditioner. The supply air flows through this bed and is both cooled and dried by the desiccant. A small stream of desiccant, an order of magnitude smaller than the flooding rate, is

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continually recirculated between the conditioner and a regenerator where the desiccant is re-concentrated using thermal energy. Again, the desiccant flows over a bed of contact media. The desiccant is heated, typically in the range of 180 F to 210 F, before it is sprayed onto the bed. Air flows through the bed, scavenges the water vapor that is desorbed from the desiccant, and rejects it to ambient to complete the cycle.

In these traditional designs, the flooding rate in both the conditioner and regenerator was relatively high so that the entire internal area of the bed was well wetted, giving the desiccant flow sufficient thermal capacity so that its temperature did not change significantly as water was absorbed or desorbed. These characteristics were important to ensure sufficient convective heat and mass transfer areas and driving potentials. At high flooding rates, small droplets of desiccant are created and entrained by the air flowing through the bed, requiring a droplet filter or demister to prevent carryover of desiccant into the air stream.

Since the desiccant salt solutions are corrosive to HVAC metals, carryover prevention is critical, a fact that has tended to limit applications to those with trained maintenance staff on hand. A new generation of liquid desiccant cooling systems that addresses this limitation has been demonstrated in laboratory and field operation and is now being commercialized. The distinguishing characteristic of the new technology is a desiccant flooding rate that is a factor of 10 to 20 lower than the rates now used in conventional packed-bed systems. Compared to the traditional technology, the low-flow liquid-desiccant air conditioners have much lower pressure drops, are more compact, produce a greater cooling effect (e.g., lower cfm/ton), and more deeply dry the process air. An important advance is that both the conditioner and regenerator operate with zero desiccant carryover. The system typically provides more than 75% of its total cooling as dehumidification, so it is targeted to dedicated ventilation air treatment. Regeneration energy can be supplied by solar thermal collectors, a combined heat and power (CHP) system, or a combination of waste heat and compressor desuperheat. The thermal COP of these improved liquid desiccant cooling systems is approximately 0.8 with regeneration temperatures of approximately 200 F. The electrical COP is over 13.

The storage of concentrated liquid desiccant provides an effective means to match cooling loads with the availability of solar or waste heat energy while minimizing storage tank volume and eliminating insulation. The relatively low cost for desiccant storage, particularly systems that use calcium chloride, will ensure a high utilization of the thermal energy provided by solar collectors, thereby improving the competitiveness of the solar cooling system.

Solid desiccant system: Solid desiccant systems most commonly use a corrugated, rotating wheel with face seals that create two isolated air paths through the rotor. The supply air moves through one sector of the rotor, while hot regeneration air moves through the other. The rotation of the rotor permits continuous dehumidification of the supply air without valves or dampers to periodically redirect the air flows. Since there is no active cooling within the rotor and the rotor itself transfers some heat from the regeneration air to the supply air, the supply air leaves the rotor drier but at a higher enthalpy than it entered.

In most HVAC applications the dry air leaving the desiccant rotor must be cooled before it is supplied to the building. One method to accomplish the desired cooling of the supply stream is to use a combination of a heat recovery heat exchanger to preheat the regeneration stream, an indirect

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evaporative cooler, and a direct evaporator cooler. This combination can produce a dry (0.010 lbm/lbm) and cool (55 F) supply stream under hot and humid conditions.

In a recent study (Jalalzadeh-Azar et al., 2005) the performance of such a desiccant cooling system was evaluated in the context of a combined heat and power (CHP) system. The system incorporated a desiccant dehumidifier, a heat exchanger, an indirect evaporative cooler, and a direct evaporative cooler. The air flow through the desiccant wheel was balanced (equally split between the process and regeneration air streams) and rotated at near-optimal speed. (There is a potential improvement through unbalancing the wheel so that the supply airflow rate is greater than the regeneration flow.) The desiccant unit was regenerated through heat recovery from a gas-fired reciprocating internal combustion engine at a temperature of approximately 200 F.

For climatic conditions representative of Atlanta, the CHP system offered sufficient sensible and latent cooling capacities over a wide range of operation, while providing outside air in excess of what is typically required for commercial buildings. The sensible load ratio (SLR) was in the range of 0.5 to 0.8, depending on ambient conditions, which is generally lower than the SLR of commercial buildings. The desiccant system has potential for high latent load applications such as dedicated outdoor air treatment. The thermal COP was in the range of 0.3 to 0.6 and the electrical COP was approximately 5.

Hybrid desiccant-mechanical systems: Solid and liquid desiccant-enhanced vapor compression systems are in various states of development. Packaged rooftop designs are configuring the desiccant wheel downstream of the evaporator in the supply airflow to provide additional dehumidification and reheat. These systems can make use of waste heat or building exhaust to regenerate the desiccant, albeit with decreased drying potential, and should reduce the need for over-cooling. Their overall cooling efficiencies are theoretically lower than the mechanical systems on which they're based, due to the additional pressure drop of the desiccant components, but with the Sensible Load Ratio shifted towards dehumidification.

Liquid and solid desiccant HVAC systems have unique advantages for controlling humidity with little electricity. They make use of thermal energy that could be supplied by waste heat, heat rejection from a CHP system, or solar thermal collectors. The ability of a desiccant to dry air to a low humidity ratio makes it a good candidate for systems in which the ventilation air is processed separately from the circulation air.

The thermal COP of desiccant systems is in the range of 0.3 to 0.8, depending on operating conditions and climate. The electrical COP of desiccant systems is in the range of 5 to 15. Hybrid desiccant-mechanical systems are beginning to appear on the market (see references)

Renewable Energy Electric and Thermal Systems

Photovoltaic systems

Electricity produced by a variety of solar photovoltaic (PV) technologies is ideally suited for applications in commercial buildings, small and large. PV products are produced worldwide and are being applied to a widening variety of commercial building types. PV systems connected to the grid or with battery storage may be used to reduce peak loads in buildings.

Increasingly, applications include Building Integrated Photovoltaics (BIPV) in which PV

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cells/modules/arrays become structurally integrated as part of the building envelope. These integrated applications include glazing, roofing membranes (including fire rating/water proofing), spandrels, awnings/sunshades, and others. Site planning, orientation and design integration of BIPV elements are critical to the successful use of PV. Integrated modeling includes assessing the potential benefits of PV interactions with the glazing, daylighting, and hot water systems.

The cost effectiveness of solar electricity is driven by PV equipment costs, local climate conditions, electricity rates, financial and tax incentives from local, state or federal sources, and electric utility incentives that may include financial incentives and net metering (utility buyback) programs. Typical systems produce electricity that is higher than current retail prices. However, PV arrays typically produce maximum power during electricity system peak demand which substantially increases the value of the power produced.

Solar water heating

Nationwide, approximately 7% of the energy use in commercial buildings is for water heating. Solar water heating systems are an established technology that can efficiently provide up to 80% of the hot water needs. Solar water heating systems are most cost-effective for facilities in which the water heating load is substantial and constant throughout the week or year; the climate has significant solar insolation, and the cost of the fuel used to heat water is high (greater than \$10/Mmbtu or \$ 0.034/kWh).

Currently, the most feasible applications are buildings with large hot water loads such as residences, hotels, laundries, and prisons, or those buildings with swimming pools and kitchens such as schools. In general, unless an office building has a cafeteria, daycare, or some other regular use of hot water, solar water heating is not effective. Retail buildings similarly have a limited number of restrooms and clean-up facilities.

Solar water heating would be an important component for reaching an approach to zero energy use level for small buildings, and for larger ones with large hot water loads. Energy use may not be significantly reduced for commercial and retail buildings (probably on the order of 2 to 10 percent) because the loads are generally low. However, the central hot water generation systems that are typically used are inefficient for meeting the low-use, distributed loads such as lavatories. The actual end use hot water energy can equal the pumping energy. For larger buildings with modest loads, small distributed heat pump water heaters using toilet room exhaust air as the heat source or point-of-use (tankless) systems may provide savings. Typical service water heating issues are well covered in the 30% Guides and would be a good source for additional information.

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PROCESSES TO ACHIEVE SIGNIFICANT ENERGY SAVINGS

The Scoping Committee assessed the processes that would lead to the design of net zero energy building. There are two aspects to this assessment which the Guide Project Committee needs to include in the guides.

Methodology from 30 % Guides for Achieving a Low Energy Building:

Chapter 2 of the 30 % Guides describes the methodology for achieving a 30 % energy reduction in commercial buildings. The approach is entitled an “Integrated Process” and is basically the same as the Integrated Design Process discussed in the next section. The material in Chapter 2 does not stress the importance of including the building owner in the design process from the start nor the need to develop a building model to explore alternatives, both of which are very important in the more complex designs needed to achieve net zero energy use. This is essential for larger and more complex buildings. Chapter 2 is relevant to the Net Zero Energy Use Guides and the methodology contained in it is summarized below.

Pre-Design Phase – Prioritize Goals: The energy goals and general strategies need to be documented in this stage to guide the team and provide benchmarks during design and construction. The energy goals should relate to the large energy uses in which the largest saving can be achieved. The major uses differ depending on climate. The four energy goals are:

1. Reduce loads on energy-using systems
2. Size HVAC systems for reduced loads
3. Use more efficient systems
4. Exploit maximum system integration opportunities

Table 2-1 contains a number of detailed strategies and recommendations to achieve these goals. The goals are equally valid for the Net Zero Energy Use Guides, but the strategies will need some tailoring to address the zero energy use criterion.

Design Phase: This is a critical phase in which the design team converts energy strategies into building plans, sections, details, and construction. The sequence of the design decisions has a major impact on energy efficiency, and critical decisions must be made early in the process. Page 8 of the 30 % Guides lays out a design sequence with the appropriate time to address energy reduction measures. For higher performance buildings, one important addition to the process laid out will be to include the owner earlier and in more of the steps. Another addition will be the development of a detailed building model to aid selection of the most energy efficient and cost-effective alternatives. For smaller buildings, some promising spreadsheet methods are emerging, but larger buildings will generally require hourly simulation programs.

Construction: The need to execute correctly the construction plans and specifications is emphasized. A sequence to achieve this is laid out on page 9 of Chapter 2. Continual verification that the construction is proceeding correctly is important. Documentation of issues that arise and their resolution is necessary.

Acceptance: This is the final stage of construction in which the project team and an independent party verify that the systems are operating as intended. Third party commissioning is recommended as part of this quality-assurance process.

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Occupancy: During the first year of operation the building operator reviews the overall operation and performance of the building. Systems that are not performing as expected are discussed with the design and construction teams and the issues are resolved during the warranty period. During this phase, using the building model to make a comparison between actual and expected performance is advised to provide feedback to the design and construction teams.

Operation: Energy use and changes in the building and its operation are documented to ascertain that the building and systems are operating at peak performance. It is essential to recommend energy tracking measures in the design and construction phases and follow through to include them in the operational stage. The performance data needs to be conveyed to the end user to provide a quantitative assessment of performance and allow action to maintain the expected efficiency levels to be taken. This step will need to be expanded on in the Net Zero Energy Use Guides to possibly include the use of the building model in assessment.

Integrated Design Process

The integrated design process is the key to achieving a low energy building. In an Integrated Design Process there is early stakeholder collaboration that allows both better control of all aspects of a project and the greatest opportunity for early sharing of expertise. Integrated design is in contrast to the traditional method, where an architect takes the lead and there is a limited role played by consultants, mechanical and structural engineers, and the other professionals at the Schematic Design Stage. While the traditional method may be appropriate for buildings designed to achieve relatively low levels of energy reduction, an Integrated Design Process must be used for buildings requiring significant energy reduction. The collaborative nature of the Integrated Design Process compared to the linear nature of the conventional design process is shown in Figure 4.

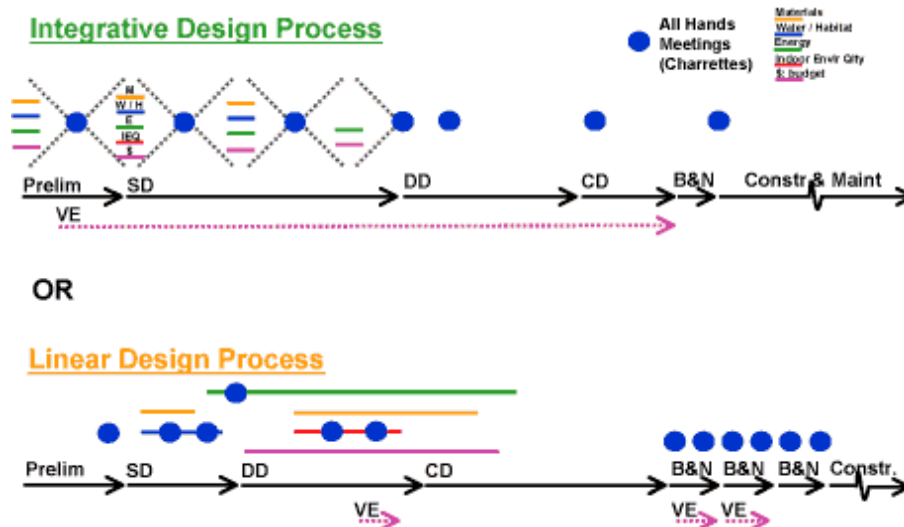


Figure 2. Comparison of the Integrated Design and Linear Design Processes
(Courtesy of William Reed, Integrative Design Collaborative)
Legend: SD: Schematic Design; DD: Design Development; CD: Construction Documentation; B&N: Bidding & Negotiation; VE: Value Engineering

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The basic steps in the Integrated Design Process are:

- Individual experts initially develop a rough understanding of the issues of the project before meeting. These include ecological systems, energy systems, water systems, material resources, and skill resources. This allows the design process to begin with a common understanding of the base issues.
- These experts come together in the first charrette with the building owner to compare ideas, set performance goals, and begin to form a cohesive team to function as co-designers. As equal players they allow for a more integrated and optimized project.
- The team members then work individually on their respective issues, refining the analyses and comparing notes and ideas in smaller meetings.
- The team reassembles for a deep discussion of overlapping benefits and opportunities, such as how best to utilize the “waste” products from one system to benefit other systems. New opportunities are explored and new questions are raised.
- Team members go apart to design and analyze with more focus, allowing more potential benefits accrue. New ideas are uncovered.
- The team reassembles to further refine the design and optimize the systems they are using (building and mechanical systems).
- The process continues until the iterations move as far the team and client wish.

Good integration is a continuously iterative process. All issues need to be kept in play so that the connections and relationships can be optimized. A linear process approaches each problem directly and sequentially, while in an integrated process each problem is approached from the different viewpoints of the participants and the issues they represent. It is a continuous circling process to make sure the project is exploring the best opportunities and adjusting responses as more understanding

The integrated design process is intrinsically time and data intensive as it will involve more modeling and simulation than current design methods. The interactions between many team members will be facilitated with the creation of a shared Building Information Model, BIM, early in the design process. The BIM will evolve over time, capturing the progressive development of the building design in a manner that allows each team member to engage in the necessary analysis and decision making using the same building data. The BIM should be used and updated in the construction and commissioning process, and ultimately used by the owner for facility management, maintenance and operations. BIMs are now widely discussed in the A/E community and the NIBS is developing a National BIM standard largely focused on geometrical and architectural detailing, but intended to eventually fully support all MEP systems.

The results of early collaboration lead to buildings that will reduce energy waste and achieve comfort and functionality with the minimum of support. This collaboration, by dealing with a unified strategy, can directly affect building form, the nature of the envelope, mechanical, electrical and other systems. Integrated Practice, which connects practice, design, and technology, is seen as an essential strategic initiative by the American Institute of Architects.

Integrated Practice was used in the design of a double envelope façade in the C.K. Choi Building in Vancouver B.C. The natural ventilation and cooling strategies incorporated in the building can reduce energy costs 10-25% versus conventional systems. (Ecological Engineer Vol 1: KEEN Engineering by Macaulay & McLennan, Ecotone Publishing 2006, p 107)

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There are many anecdotal reports of the value of an integrated design as well as a formal assessment in the DOE/NREL reports on the six low energy buildings. A number of practitioners speak to the benefits of Integrated Practice/Design:

“It is much easier and cheaper to maximize the benefits of green planning and design by addressing issues in the initial stages of the project” (*Rocky Mountain Institute RMI 1998*)

“When a series of linked efficiency technologies are implemented in concert with each other, in the right manner and proportions, there is a new economic benefit to be reaped from the whole that did not exist with the separate technological parts” (*Home energy Brief RMI 1994*)

“As a general rule, the opportunities for creatively addressing solutions occur very early in the design process (the later in the design process, the more expensive the implementation).” (Richard Keleher, *Parametric Daylighting/energy Modeling Software Memorandum*, Mar 9, 2006)

There is an added dimension when Integrated Design is seen in relationship to Sustainable Design. This latter construct requires a different mindset or mental model and practice methodology that looks at systems in a more complex and integrated way. Instead of looking at just the physical elements of the building, the hidden connections between the elements need to be addressed. For example, these hidden connections and patterns may be manifest in the downstream impact of toxins in building materials, the multiple efficiency and cost relationships between the many variables in an HVAC system and the building envelope, or the impact on social systems due to logging practices or any raw material extraction.

In summary, the key aspects of the integrated design process are

- The owners are the motivating factor for designing an energy efficient building and need to be involved from the beginning. They set goals and make the important decisions. Their participation is needed to ensure that the architects and engineers will meet the project goals.
- A whole building Integrated Design Process in which the owner, architects, and engineers work together as a team is essential. A holistic view is needed in which all of the components are combined to yield the necessary energy reductions. Simulation of the building and the alternative systems facilitates the design process.
- Owners are responsible for the cost of the project, but they make many decisions on the basis of values, not cost. Owners will pay for features that they really want, and often cite cost to eliminate features that they do not want.
- Measurable energy goals are set at the start of the project. These should be quantitative goals such as Btu/year-ft². This allows the design team to evaluate the different approaches on a common basis. Further, post occupancy monitoring can then be conducted to ensure that the building actually meets the energy targets.
- Training and education for facility operators are included in early design meetings.
- Commissioning after the building is built together with continuous monitoring allows the performance to be verified.

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PLAN FOR DEVELOPING GUIDES TO APPROACH ZERO NET ENERGY USE

The charge initially given to the Scoping Committee was to develop techniques to allow a “50 % approach to zero energy use.” In the process of developing this report, the Scoping Committee came to a number of conclusions. It is hoped that the resulting recommendations will direct the Guide Project Committee in producing Net Zero Energy Use Guides. The Scoping Committee also has some recommendations for the AEDG Steering Committee regarding the Guide Project Committee.

Recommendations to the AEDG Steering Committee

The Scoping Committee has identified some major issues that need resolution by the AEDG Steering Committee:

1. *Promote the Integrated Design Process as essential to reach the targeted energy savings and as critical to the design of a low energy building.*

The group developing the Guides should follow this process itself, by including all of the relevant stakeholders on the Guide Project Committee. This will ensure that the developed Guides will be credible to the building design profession.

The process of reducing building energy reduction is a continuum, with more advanced or aggressive measures leading from a zero to a 100 % approach to net zero energy use. The measures described in the Guides should be viewed as an approach that will lead toward a 100 % approach as opposed to achieving an arbitrary 50 % or 70 % savings.

The measures recommended in the Guides will improve energy effectiveness of the envelope, mechanical systems, illumination, and other systems in a synergistic manner. Determining the optimal combinations will require increased time and effort in the design phase. Modeling and simulating the energy use and cost of different alternatives will be necessary. The committee believed it unlikely that the desired significant levels of energy reduction could be achieved only with a prescriptive approach such as that used in the 30% guides.

An essential component of integrated design is to address the architectural aspects early in the process. In order to achieve significant energy reductions for a given, it will be important to consider building orientation, aspect ratio, window placement, and daylighting in the design phase of the building.

The Guide Project Committee should recommend that the building design team use an integrated design approach for the building and the HVAC system. As part of this approach, the prescriptive envelope measures of the 30 % Guides need to be considered first. Then the appropriate techniques and technologies enumerated above should be incorporated, as appropriate, for the building type, size, and location. The Guide Project Committee (and building design team) should start with those measures that appear reasonable and cost effective, and then move on to more sophisticated measures. It is expected that each building will require significant analysis of different designs to determine those that are the most effective. In this step, simulation techniques will be an invaluable aid for screening the measures, providing insight, and quantifying the interactions between the different measures. For each design, the level of amenities and the cost to achieve them needs to be determined.

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The Guides should serve to educate the building owner and design team to the tradeoffs between the increased cost and effort in the design phase, the capital costs of equipment, and the reduced cost of operating the building. A life cycle costing approach will be needed that takes into account the lower energy costs over the life of the building.

2. *Decide whether to use Source Energy or Site Energy as the measure for the guide at the beginning of the Guide development process.*

As the level of approach to net zero energy use increases, the distinction between site and source energy use becomes more important. The Scoping Committee believes that source energy is the important measure, and recommends that this issue be decided by the AEDG Steering committee prior to the Guide Project Committee work.

As the target energy levels are lowered, energy production by renewables will play a prominent role. Electricity and heat generated by solar (or wind, biomass, etc.) will be essential to offset the building energy use. Energy conversion devices (microturbines, fuel cells, CHP, etc.) will increase the effectiveness of fuel use by producing electricity as well as heat. These considerations additionally lead to a source rather than a site basis for energy reduction.

3. *Review the selection of the energy use baseline.*

The approach to net zero energy use requires an energy use baseline for the building. The building built to ASHRAE Standard 90.1-1999 is recommended as the base in order to be consistent with the 30 % Guides. A determination of the expected performance will require simulation of the proposed building under the 90.1-1999 criteria, which is somewhat arbitrary. Although the “Approach to Net Zero Energy Use” is conceptually appealing, the baseline is difficult to quantify. The Scoping Committee discussed possible baseline models that might be employed, some of which are a) the actual building built to 90.1 specifications, b) a building with the same general characteristics built to 90.1 specifications, and c) a building of same floor area and function. The Scoping Committee recommends that the AEDG Steering Committee resolve this issue early on in the process.

As part of establishing the baseline, the AEDG Steering Committee needs to determine how existing and or previously written standards and guides (e.g. 90.1, 18P) relate to the AEDG series and recommend to users the guides to use in establishing a baseline.

Rather than employ the somewhat arbitrary nature of the percentage approach to net zero energy use, it could be preferable to specify the net source energy use on a per unit floor area or similar basis. Different criteria would pertain to different building types and climate zones. This would provide a more readily obtained measure than an X % net energy reduction. The Scoping Committee recommends that the final study at least map the actual net energy use levels into a metric such as use per unit floor area, accounting for occupancy and climate effects. This would facilitate the determination of whether the criterion is met.

To this point, the net energy use reductions do not include process and plug loads since neither is included in ASHRAE Std 90.1-99. However, the thermal loads resulting from such process

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sources are included as part of the A/C loads. Some of the other sources (NBI, NREL) include the plug loads in determining the approach to net zero energy use. The Scoping Committee recommends that a standardized realistic set of process and plug loads be included in the energy use evaluation. These loads are a significant part of the energy consumption and their reduction is important to achieving a sustainable building.

4. Clarify the target audience(s) for the Guide(s).

The AEDG Steering Committee should attempt to involve and educate the ASHRAE membership in some fashion. The measures discussed are all in the ASHRAE sphere of interest and the membership has the potential to make contribution at the beginning of the process.

The size and/or complexity of a building will influence the skill and tools required in design. For smaller and less complex buildings, it is possible that relatively simple rules and specifications will suffice, especially as experience is gained from meeting the energy reduction goals. However, it is not expected that a purely prescriptive approach will produce the desired energy reductions for larger and more complex buildings in all locations.

For large and complex buildings, the emphasis on an integrated design approach with very aggressive performance targets means that the Net Zero Energy Use Guides will probably not be employed initially by the entire profession. Conceptually, the engineering design community can be placed into the four quadrants indicated in Figure 5. “Tools” include simulation techniques and the ability to perform system analysis. The Net Zero Energy Use Guides will initially be suitable for the top half and lower right quadrants.

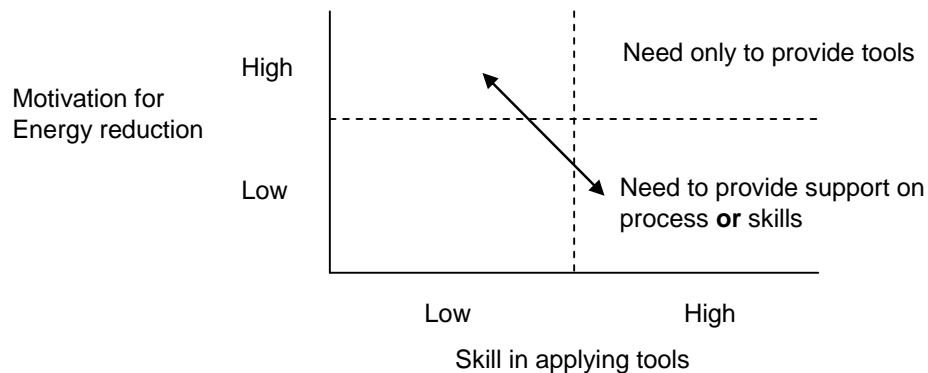


Figure 3. Conceptual relationship between motivation and skill in the design community

As experience is gained by the Guide development team and the building community with applying the Guides, additional tools, techniques, and measures will evolve and appear. It is anticipated that simulation and analysis techniques necessary to evaluate the building performance will develop further and become easier to use and more widely available. Sets of appropriate measures will be generated that will provide specific direction for certain building types and locations. The building industry is not static and new measures will be created. The profession is expected to sort through and identify those systems and components that produce the greatest energy reductions. As a result, the use of the Approach to Net Zero Energy Use Guides will eventually penetrate the lower left-hand quadrant.

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5. *Creation of a Guide Project Committee*

Appoint the Guide Project Committee as soon as possible, and at least by the time of the Dallas Winter Meeting, January 2007. This Scoping Committee report should provide enough guidance for a committee to be formed and for the members to initiate discussion of the issues. The committee should include the relevant players in an Integrated Design Process.

Create a sub-committee of the Steering Committee patterned along the lines of a ASHRAE Project PMS to work closely with the Guide Project Committee. They should have the Guide development as their sole responsibility and be responsible for oversight and guidance of the Guide Project Committee.

Establish a budget for the developing the Guides. This money would be “real” if the work were to be contracted out or would be “in kind” if the work is done voluntarily. A rough budget for the initial phase of the work is about \$ 400,000, arrived at as follows:

8 case studies @ \$ 15,000 each	\$ 120,000
<u>12 simulations</u>	<u>\$ 80,000</u>
Development of two Guides	\$ 200,000

6. *Development of Guides*

Instead of or in addition to the Guides for different building types, the Steering Committee should consider developing a set of documents that deal with different aspects of low energy buildings. These documents could include the following topics:

- Envelope treatments
- Controls and optimization
- Daylighting and illumination
- Mechanical systems (primary and secondary)
- Simulation and evaluation tools

Consider options to complete case study work. The project to evaluate a number of case studies of "normal" low energy buildings in some detail will take time in order to do a careful and exhaustive evaluation. It is certain that more data on case study projects would be very helpful. Two possible options to complete the case study work relatively soon are: 1) One of the existing committees undertake this work as additional background (e.g. similar to our scoping committee or the steering committee) or 2) A new committee be charged to undertake this assessment and provide information to the Steering Committee. The summer of 2008 is a realistic time to complete a detailed guidance document.

7. *Address lighting standards*

Establish a broad interest committee composed of the major stakeholders in the electrical lighting field to explore lighting recommendations that set appropriate levels for the tasks at hand. The electrical lighting area is one with opportunities for significant reduction in energy use. Currently, lighting designs follow a prescriptive standard. An alternative performance approach, such as the “performance-based” design approach of 90.1, does not exist for lighting.

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Additional Information Needs for the AEDG Steering Committee to Investigate

During the course of the Scoping Committee work, a number of issues arose in which information was lacking. The Scoping Committee has identified several projects that would supply information that is expected to be needed to carry out the development and application of the Guides. These projects are described below:

1. Develop adequate screening tools for advanced energy reduction measures. Such tools would allow a determination of the measures that are and that are not appropriate for a given situation (building type, size, and location).. The tools should allow for a relatively simple data input (not full-blown simulation) and as output provide an estimate of the relative energy savings of different measures and their ranking.
2. Determine parasitic power requirement benchmarks for air and water distribution systems. This would be an evaluation of the realistic minimum power requirements for air and water systems that could be set as energy targets (e.g. 5 kW/ton of air conditioning). The desired information would consist of metrics such as gpm/ton, cfm/ton, W/ton, etc. for transport energy.
3. Develop and evaluate systems in which the heating and cooling is separated from the dehumidification and ventilation.
4. Develop techniques for monitoring or metering that would provide the energy consumption of separate components such as lights, compressors, plug loads, tenant loads, etc. The methodology could be a combination of modeling and measurement.
5. Develop information on the implementation of continuously dimmable ballasts. This would involve determining the costs, reliability, energy use, installation of sensors, control techniques, etc. This information would allow a realistic assessment of the energy savings due to daylighting to be made.
6. Develop realistic and obtainable performance goals that can be measured. These would include target values for system size (ft²/ton, etc), distribution efficiency (W/cfm or ft², etc), and other important areas.
7. Determine the relationship (if one exists and is general) between peak equipment sizing and annual energy use. Determine whether this could be a quick method for estimating the impact of components on energy use.
8. Develop quick and accurate methods for calibrating a model of a building so that the model can be used with confidence to explore alternative measures.
9. Evaluate overall heating system performance. Two opposing approaches were identified. A high supply temperature of the heat transfer fluid may not significantly impact boiler or furnace efficiency and can dramatically reduce the transport energy. Alternatively, the use of condensing boilers and “outdoor reset” or equivalent control strategies to reduce the temperature of the circulating water/brine to the lowest temperature that will meet the needs may yield better performance.

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Suggested Approaches on Guide Development for the Guide Project Committee

The Guide Project Committee needs to emphasize the tradeoffs between the increased effort in design and the longer term benefits. Experience with the Integrated Design Method has shown that the design costs may be higher but that there are savings in equipment and energy costs. These aspects are discussed in the section on Integrated Design.

We suggest that the committee charged with developing the Net Zero Energy Use Guides follow the plan outlined below. The Scoping Study Committee proposes three approaches that the Guide Project Committee could follow, each with its own merits:

- a. Develop one prototypical building model (e.g. an office building) with a range of sizes and simulate it in a range of climates to explore the impact of different measures on the energy use. This initial exercise will provide experience on the limits of performance and give insight into the viable measures.
- b. Using the 20,000 ft² building models used to develop the 30 % Guides (office, retail, school, etc.), determine how far first the prescriptive measures and second the measures in this report can go toward reducing the net energy use. This will be an easily conducted first step in assessing the impact of various measures, but it will be limited to relatively small and simple buildings.
- c. Using a case study approach, identify 2- 5 actual office, retail, or school buildings for which a model exists and where there is measured performance and documented equipment costs. Verify the computer models against actual performance measurements. Then, through simulation, determine the benefits of the existing and additional measures. This approach will establish confidence that simulation can be used to predict performance goals and identify the impact of some measures.

In order for the development of the Guides to be successful, it is important to determine how buildings are actually used. The case study approach could provide valuable information on occupancy, operational schedules, etc., and feedback from the owner, engineers, occupants etc. as to whether the measures that have led to low energy use are satisfactory to them. Results from the 2-5 buildings proposed under the third approach would be helpful in establishing measures that work, but information on many more buildings is needed in order to make general recommendations.

The Scoping Study Committee developed the following plan for the first alternative (a), in which one prototypical building model with a range of sizes is evaluated. It could be modified if the Guide Project Committee decided on one of the other options.

1. Establish a set of prototypical office buildings. It is recommended that one of this set be the 20,000 ft² building used in the 30 % guides, and that two other prototypical buildings of 50,000 ft² and 200,000 ft² be established. The choice of building sizes was taken from the EIA website, which states that roughly one-quarter of the energy use is in buildings of less than 10,000 ft², 40 % in buildings between 10,000 and 100,000 ft², and one-third in buildings over 100,000 ft².
2. Establish baseline energy use for the three prototypical buildings designed to ASHRAE 90.1-1999 levels. Simulate the performance of the three buildings in a few climate zones (e.g. climate zones representing Seattle, Phoenix, Miami, and Duluth).

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3. Analyze the baseline results to determine the contribution to energy use of the major components (i.e. envelope, ventilation, HVAC system). Identify the measures from those listed in this report that could readily be employed to yield significant performance improvements in each of the areas of major energy use.
4. Establish a set of quantifiable measures for baseline energy use for different buildings and different climates.
5. Determine the cost associated with each of the measures. This will allow the costs and benefits of each measure to be determined.
6. Identify design, construction, commissioning, and operating issues.
7. Select promising measures from those enumerated above and perform simulations in the different building types for the climate zones. This will be a further sorting exercise. It is expected that demonstrating the potential of different measures in a few (e.g. four) rather than the nine zones used in the 30 % Guides will be sufficient.

The goal for each of the applied measures is to achieve as much energy savings as possible. There is a point of diminishing returns for each component idea for which the benefits are less than the cost. Measures that can produce step reductions in energy use need to be found and evaluated. For example, a GSHP will have a large benefit over an air source heat pump.

It is important to realize that there is a synergy between the measures and that the simulations need to include the interactions between the measures.

8. Assess the results of the simulation of the prototypical office buildings and generate general ideas about the viability of different measures. The observations of the contributions of the different measures to energy reduction will be valuable in performing the next steps. The measures that are not appropriate will also be identified.
9. Establish a set of prototypical buildings for different building types. The aggregate energy reduction potential was identified in the DOE/NREL study (Griffith et al., June 2006) as greatest for warehouses, office, and educational facilities, medium for retail, public assembly, strip malls, service, religious, lodging, and food service facilities, and lowest for health care, enclosed malls, and laboratories. The FW Dodge data shows that historically the greatest number of building starts were for, in order, apartments, warehouses, retail, office, and schools.

We recommend that the Guide Project Committee develop additional prototypical buildings for warehouses, retail, and schools. We recommend that three prototypical buildings of small, medium and large sizes be developed; the actual floor area for each type should be based on the data for existing and new buildings. The smallest buildings would be those used to develop the 30 % Guides, which would establish some continuity in the Guides.

10. Follow the same process for each of the prototypical building types as for the office buildings (Steps 2, 3, 4, and 5).

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Additional Support Projects for the Guide Project Committee

Simultaneously to the development of the actual Guides, the Guide Project Committee should undertake the following supporting projects:

1. Establish a process for selection of measures on a cost/benefit basis which may require an evaluation of the tools used to determine the performance and costs of measures and a determination of the relative value of using public domain tools versus proprietary tools (TRACE, HAP, etc).
2. Develop a large set of case studies that would demonstrate that significant (over 50%) energy savings can be achieved and be cost effective and illustrate the benefits of Integrated Design.
3. Consider at least two separate guides: The first could be for buildings with the budget for the full process with a sophisticated design team and the second for fast track buildings with a limited budget. Care is needed in developing the “fast-track” document that it not be limiting in terms of energy savings potential.
4. Consider also an initial guide based on case studies. These case studies would illustrate the integrated design process and methods. It would focus primarily on larger buildings. Case studies would demonstrate technologies and methods and would also show optimization of examples. The case studies would be chosen to cover the range of technologies recommended.
5. Consider web based publication for the Guides. This would allow the Guides to be readily updated and modified as new techniques emerge.
6. Consider screening tools that would emerge during the development of the Guides. These could be a performance based scorecard approach and could be offered as a web application on a licensed basis.
7. Keep in mind that it is anticipated that the final Guides will contain a methodology useful for all building types. It is possible that there will be certain measures (e.g. ventilation) that will be common to all building types, and that there will be other measures (e.g. solar water heating) that will be specific to one or more types. It may be feasible to develop a “Maximum Approach to Net Zero Energy Use Guide” that will be applicable to all building types in all climates, with the degree of approach dependent on the level and number of the measures employed.
8. Be aware of complementary building studies that are ongoing, during the Guide development process. NBI has undertaken an initiative that is a series of roughly 100 page guides by technology (controls, fenestration, mechanical system optimization, ventilation, modeling, etc.) to fill a need to provide technical knowledge for those with limited budget/resources for research. DOE is creating a series of building prototypes representative of the commercial stock that may be useful. LBNL is initiating a benchmarking project for the California Energy Commission that uses utility data from 3000 commercial buildings together with calibrated building models to generate energy use intensity benchmarks at the system end-use level for major commercial building types, sizes and climates in California.

FINAL REPORT

SELECTED REFERENCES

High Performance Buildings

“Energy Savings Potential of Commercial Building HVAC Systems. Volume III Energy Savings Potential,” TIA Reference No. 68370-00, prepared for Building Technologies Program, DOE, July 2002

Griffith, B, P. Torcellini, and N. Long, “Assessment of the Technical Potential for Achieving Zero- Energy Commercial Buildings,” NREL/CP-550-39830 June 2006

New Buildings Institute Data Base <http://www.advancedbuildings.net>

Torcellini, P., S. Pless, M. Deru, and D. Crawley, “Zero Energy Buildings: A Critical Look at the Definition,” NREL/CP-550-39833, June 2006

Torcellini, P., S. Pless, M. Deru, B. Griffith, N. Long, and R. Judkoff, “Lessons Learned from Case Studies of Six High-Performance Buildings”, NREL/TP-550-37542, June 2006

Evaluation of Energy Reduction Measures

Emerging Energy-Saving Technologies and Practices for the Buildings Sector as of 2004, [H. M. Sachs](#), [S. Nadel](#), [J. T. Amann](#), M.I Tuazon, and [E. Mendelsohn](#): ACEEE; L. Rainer: Davis Energy Group; G. Todesco, D. Shipley, and M. Adelaar: Marbek Resource Consultants, ACEEE, August 2004

National Energy Modeling System for AEO 2005, Feb. 2005; BTS/A.D. Little, Energy Consumption Characteristics of Commercial Building HVAC Systems

Volume I National Lighting Inventory and Energy Consumption Estimate, Sept, 2002

Volume II: Thermal Distribution, Auxiliary Equipment, and Ventilation, Oct. 1999

Volume III Energy Savings Potential, July, 2002

California Building Energy Reference Tool. See <http://poet.lbl.gov/cal-arch/>

Fenestration Impacts See <http://www.commercialwindows.umn.edu> and go to Facade Design Tool

Building/Envelope Measures

Insulation

“Advanced Energy Design Guide for Small Office Buildings,” ASHRAE, 2004

Fenestration

ASHRAE Handbook of Fundamentals, Fenestration, Chapter 31, 2005

Lee, E., S. Selkowitz, C. Kohler, V. Bazjanac, V. Inkarojrit, “High-Performance Commercial Building Facades,” LBNL 50502, 2002

University of Minnesota/Lawrence Berkeley National Laboratory, Windows for High Performance Commercial Buildings; (<http://www.commercialwindows.umn.edu/> www.NFRC.org)

Lighting and Integration of Daylighting with Lighting

Alman, D.H., *J. Illum. Eng. Soc* 7(1) 55-62, 1977

Bierman, A, US patent 6,583,573, 2003

Boyce, P.R., Lighting control: The user’s point of view, *Lighting Controls*, Proceedings of the CEA/DBR Symposium, Ottawa, Rea, M.S. (ed.) 69-85, 1984.

Bullough, J.D, and Rea, M.S., *Lighting and Lighting Systems*, *The Optics Encyclopedia*, Vol. 2, (Brown, T.G., Creath, K, Kogelnik, H., Kriss, M.A., Schmit, J., and Weber, M.J. (eds), Wiley-VCH, Weinheim, 1323-1336, 2004

Dillon , R.F., Pasini, I.C., and Rea, M.S., Survey of visual contrast in office forms, *Commission Internationale de l’Eclairage (CIE) Proceedings*, Venice, 74-77, 1987

FINAL REPORT

- Jennings, J.D., F.M. Rubinstein, D. DiBartolomeo, S. Blanc, "Comparison of Control Options in Private Offices in an Advanced Lighting Controls Testbed," LBNL 43096, 2000.
- Lawrence Berkeley National Laboratory, Daylighting the New York Times HQ Building; (http://windows.lbl.gov/comm._perf/newyorktimes.htm), 2005
- Lee, E.S, S.E. Selkowitz, G.D. Hughes, D.A. Thurm, "Market Transformation Opportunities for Emerging Dynamic Facade and Dimmable Lighting Control Systems," ACEEE Summer Study on Energy Efficiency in Buildings, LBNL 55310, 2004.
- Lighting Research Center, Reducing Barriers to Use of High Efficiency Lighting Systems (<http://www.lrc.rpi.edu/researchtopics/reducingBarriers/resources.asp>), 2004a
- Lighting Research Center, Daylight Dividends, (<http://www.lrc.rpi.edu/programs/daylightdividends/>), 2004b
- Rea and Ouellette, *Ltg. Res. Tech.*, 23(3), 135-144, 1991.
- Rea, M.S. and Bullough, J.D., Application efficacy, *J. Illum. Eng. Soc.*, 73-96, 2001
- Ruck, N., et al, "Daylight in Buildings. A Source Book on Daylighting Systems and Components," LBNL 47493, 2001
- Rubinstein, F, R. Verderber, G. Ward, "Photoelectric Control of Daylight-Following Lighting Systems," LBNL 24872, 1989
- Rubinstein, F, N. Colak, J. Jennings, D. Neils, "Analyzing Occupancy Profiles from a Lighting Controls Field Study," CIE Session, LBNL 52344, 2003
- Smith and Rea, Commission Internationale de l'Eclairage (CIE) Proceedings, Kyoto, CIE, 207-211, 1980.
- U.S. Department of Energy (DOE), U.S. Lighting Market Characterization, Volume 1: National Lighting Inventory and Energy Consumption Estimate, Prepared by Navigant Consultants, 2002.

LEDs

- <http://www.lrc.rpi.edu/programs/solidstate/index.asp>
<http://www.netl.doe.gov/ssl/PDFs/LED-FAQ.pdf>

Distribution Systems

Reduced parasitics

- ASHRAE 2003 Handbook: Applications*. Chapter 41 Supervisory Control Strategies and Optimization. ASHRAE: Atlanta.
- Diamond, R., C. Wray, D. Dickerhoff, N. Matson, and D. Wang. "Thermal distribution systems in commercial buildings," Lawrence Berkeley National Laboratory Report, LBNL-51860, 2003.
- Fisk, W.J., W.W. Delp, R.C. Diamond, D.J. Dickerhoff, R. Levinson, M.P. Modera, M. Nematollahi, D. Wang. 2000. "Duct systems in large commercial buildings: physical characterization, air leakage, and heat conduction gains," *Energy and Buildings*, 32(1):109-119. LBNL-42339.

Ventilation

- Brandemuehl, M.J. 1999. HVAC System Design Strategies to Address Indoor Air Quality Standards. EPRI TR-114262. Electric Power Research Institute, Palo Alto, CA,
- Brandemuehl, M.J. and J.E. Braun. 1999. Impact of demand-controlled and economizer ventilation strategies on energy use in buildings. *ASHRAE Transactions* 105(1):39-44.
- Carrier Corporation Commercial Products: Energy Recycler (Carrier TM), MoistureMizer (Carrier TM), Humidi-Mizer (Carrier TM). <http://www.carrier.com>

FINAL REPORT

- Jeong, J., S.A. Mumma, and W.P. Bahnfleth. 2003. Energy conservation benefits of a dedicated outdoor air system with parallel sensible cooling by ceiling radiant panels. *ASHRAE Transactions* 109(2):627-636.
- Khattar, M.K., and M.J. Brandemuehl. 2002. Separating the V in HVAC: A dual-path approach. *ASHRAE Journal* 44(5):37-43.
- Krarti, M. and M. Al-Alawi. 2004. Analysis of the impact of CO₂-based demand-controlled ventilation strategies on energy consumption. *ASHRAE Transactions* 110(1):239-251
- Mercer, K.B., and J.E. Braun. 2005. Evaluation of demand-controlled ventilation and enthalpy exchangers in small commercial buildings. *ASHRAE Transactions* 111(1):873-889
- Mumma, S.A. and J. Jeong. 2005. Field experience controlling a dedicated outdoor air system. *ASHRAE Transactions* 111(2):433-442.
- Morris, W. 2003. The ABCs of DOAS dedicated outdoor air systems. *ASHRAE Journal* 45(5):24-29.
- Niu, J. and L. Zhang. 2002. Potential energy savings for conditioning fresh air with a membrane-based energy recovery ventilator *ASHRAE Transactions* 108(1):54-63.
- Roulet, C.A., F.D. Heidt, F. Foradini; and M.C. Pibiri. 2001. Real heat recovery with air handling units. *Energy and Buildings* 33(5):495-502
- Stanke, D. 2005. Standard 62.1-2004: Designing dual-path, multiple-zone systems. *ASHRAE Journal* 47(5):20-30.
- Taylor, S.T. 2006. CO₂-based DCV using 62.1-2004: Demand-controlled ventilation *ASHRAE Journal* 48(5):67-75.

Natural Ventilation

G.Z. Brown et al, Natural Ventilation in Northwest Buildings, 2004

Primary Systems

Ground source heat pumps

- Cane, Doug 1998. Operating Experiences with Commercial Ground-Source Heat Pump Systems. ASHRAE, Atlanta GA.
- Cane, Doug, H. Sachs, and others 2002. Commissioning, Preventive Maintenance, and Troubleshooting Guide for Commercial Ground-Source Heat Pump Systems
- Kavanaugh, S.P and K. Rafferty 1997. Ground-Source Heat Pumps - Design of Geothermal Systems for Commercial and Institutional Buildings. 167 pp. ASHRAE, Atlanta GA
- ASHRAE 1995. Commercial/Institutional Ground-Source Heat Pump Engineering Manual. ASHRAE, Atlanta GA
- Sachs, H. M., 2002. Geology and Drilling Methods for Ground-Source Heat Pump Installations: An Introduction for Engineers. ASHRAE, Atlanta, GA.

Evaporative Cooling

- Costelloe, B., and D. Finn. 2003. Indirect evaporative cooling potential in air-water systems in temperate climates. *Energy and Buildings* 35(6):573-591
- Hunn, B.D., and J.L. Peterson. 1996. Cost-effectiveness of indirect evaporative cooling for commercial buildings in Texas. *ASHRAE Transactions* 102(1):434-447.
- Maheshwari, G.P., F. Al-Ragom, and R.K. Suri. 2001. Energy-saving potential of an indirect evaporative cooler, *Applied Energy* 69(1):69-76.

FINAL REPORT

Yu, F.W., and K.T. Chan. 2005. Application of direct evaporative coolers for improving the energy efficiency of air-cooled chillers. *Journal of Solar Energy Engineering*, 127(3):430-433

Desiccant dehumidification and cooling

Lowenstein, A., S. Slayzak, and E. Kozubal, "A Zero Carryover Liquid-Desiccant Air Conditioner For Solar Applications," Proceedings Of Isec2006 ASME International Solar Energy Conference July 8-13, 2006, Denver, Co

Jalalzadeh-Azar, A., S. Slayzak, R. Judkoff, T. Schaffhauser, and R. DeBlasio, "Performance Assessment of a Desiccant Cooling System in a CHP Application Incorporating an IC Engine," IJDER, 2005

Solid desiccant wheels integrated with mechanical air conditioning have been developed by Munters HCU and Trane CDQ

Dr. Steven Slayzak, NREL, <Steve.Slayzak@nrel.gov>, Personal Communication:

Renewable Energy Electric and Thermal Generation Systems

Photovoltaic systems

U.S. Department of Energy website: www.eere.energy.gov

BIPV: *Building-Integrated Photovoltaic Designs for Commercial and Institutional Structures: A Sourcebook for Architects.* www.nrel.gov/docs/fy00osti/25272.pdf

Federal solar tax credits handbook: Solar Energy Industry's Association
www.seia.org/manualdownload.php

State-level solar incentives: www.dsireusa.org

Solar water heating

Whole Building Design Guide Website <http://www.wbdg.org/design/swheating.php>

Integrated Design References – could use some more definitive references

"Advanced Energy Design Guide for Small Office Buildings," ASHRAE, 2004

Allison Garwood: Autodesk paper 2007

Bill Read: Market Transformation to Sustainability Guideline Standard: The Whole System – Integrative Design Process, unpublished paper 2007.

Opt E Plus by NREL indicates criteria when reaching 50% or above will require significant input by mechanical and electrical engineers into the design.

Norman Foster in the design of "skygardens" and "graduated mediation" – exterior dual wall systems – in the use of natural ventilation in high-rise buildings.

NREL Reports on the DOE/NREL buildings:

Adam Joseph Lewis Center for Environmental Studies, Oberlin College, Oberlin, Ohio:

www.nrel.gov/docs/fy05osti/33180.pdf

Zion National Park Visitor Center Complex, Zion National Park, Utah:

www.nrel.gov/docs/fy05osti/34607.pdf

BigHorn Home Improvement Center, Silverthorne, Colorado:

www.nrel.gov/docs/fy05osti/34930.pdf

NREL Thermal Test Facility, NREL, Golden, Colorado:

www.nrel.gov/docs/fy05osti/34832.pdf

Cambria Office Building, Ebensburg, Pennsylvania: www.nrel.gov/docs/fy05osti/34931.pdf

Chesapeake Bay Foundation Building, Annapolis, Maryland:

www.nrel.gov/docs/fy05osti/34830.pdf

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APPENDICES

1. Charge from the AEDG Steering Committee 10/25/05
2. Potential for Achieving a Net Zero Site Energy Building
3. Current High Performance Buildings
4. Impact of Technologies
5. Issues in Lighting

Appendix 1: Charge for Advanced Energy Design Guide Scoping Study Committee

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Charge for Advanced Energy Design Guidance 50% and 75% Scoping Effort
10/25/05

Background

ASHRAE, in conjunction with its partners AIA, IESNA and USGBC are currently working on the development of a series of Advanced Energy Design Guides (AEDGs) for small commercial buildings which target 30% energy savings relative to buildings designed to meet the requirements in energy standards in effect at the turn of the millennium (Standard 90.1-1999). Once this series of guides is complete, the partnership will embark on the development of a series of AEDGs that target a 50% energy savings. Subsequently an effort will be launched to develop guides that target 75% energy savings. As such, the scoping effort should address the needs for both the 50% and 75% documents.

It is recognized that achieving the 50% and 75% savings targets will likely require some research efforts. As such, a scoping study is proposed to identify the data and research needs necessary to support development of the 50% and 75% AEDGs. This document outlines the issues that the scoping study should address.

ASHRAE resources have been allocated to support a small group effort including travel funds for meetings and additional funding to cover a facilitator if needed.

Guidance for Scoping Effort

The scoping study should outline what is known about achieving highly energy efficient buildings as well as what needs to be developed in order for a project committee to produce an AEDG for a class of buildings. The scoping effort must also bear in mind the nature of the target audience for an AEDG and the types of buildings and their systems when developing their recommendations. For the AEDGs that target 50% and 75% savings levels the target audience is likely to be more focused on design professionals due to the emphasis on integrated design. In addition, the 50% and 75% documents will likely be more applicable to larger building sizes than those used in the 30% guides.

Some suggested steps in completing the scoping effort are:

- Literature search – Identify what is available and what is known relative to high energy performing buildings. What has been identified as still needing to be done? The literature search should focus on projects with measured energy performance to demonstrate that design intent was met (or not).
- Consider the applicability of the ASHRAE Strategic Research Plan to this scoping effort
- Consult with organizations in the energy efficiency field to gain input on what they see as needing to be done (e.g. DOE, EPA, CERL, ACEEE, NBI, NRDC, CEE and Energy Efficiency programs from utilities)

- Review sources for new energy efficiency technology for technologies and applications suitable for incorporation into a 50% AEDG. Identify any limitations on their use.
- Determine whether reaching a 50% or 75% target can best be accomplished using prescriptive vs. performance approaches.
- Determine whether any tools will be necessary to facilitate meeting the 50% and 75% targets (e.g. tradeoff methodologies, new algorithms).
- Address the issue of integrated design and the tradeoffs associated with that. This should include the areas of building form and orientation as well as the integration of the mechanical, lighting and envelope systems.
- Consider the merits of incorporating recommendations for specific mechanical systems as well as identifying the tradeoffs these systems. Consider whether some mechanical systems might be inappropriate at the higher energy savings levels.
- Address the issue of whether renewable energy should play a key role in the 50% and 75% AEDGs. If renewable energy is to be incorporated, how should it best be incorporated? Consider whether projects built to the recommendations of these guides will require a minimum percentage of on-site renewable energy in order to meet the requirements of net-zero energy buildings.
- Recommend methods for addressing tenant-added items and how they affect building energy use.

The scoping study should identify any specific research needs and propose a plan for accomplishing that research in a timely fashion. The recommendations should not be limited solely to what might be accomplished through ASHRAE's current research program. In addition, the scoping study should speculate on when the necessary data and research might become available in order to facilitate development of the 50% and 75% AEDGs.

Deliverables and Timeline

January 2006	Annotated outline of scoping document
April 2006	Documented results of literature search
June 2006	Draft report on scoping exercise
October 2006	Final scoping study report

Appendix 2: Potential for Achieving A Net Zero Site Energy Building

NREL has conducted a building sector analysis with high level parameters to evaluate a number of promising technologies (Griffith et.al., June 2006). The methodology was to create a large number (greater than 5000) of building models of all types, based on the 1999 CBECS data set. A high-level set of parameters was used for the buildings and the building energy use was then calibrated to the CBECS data set. These models were then exercised with different technology options in different regions of the US to determine the maximum site energy reductions possible.

The scenarios evaluated were:

- Base Case. This is the reference building with 90.1- 2004 characteristics.
- Base Case with PV. The reference building with 10 % efficient PV cells applied to 50 % of roof area.
- LZEB 2005. Aggressive technologies that are currently available (2005) were applied to building. These include daylighting, T-8 lighting, super-insulation, central water-based chiller with a COP of 6, and VAV systems.
- LZEB 2025. Similar to LZEB 2005 but with the technological improvements expected to be available by 2025.
- LZEB 2025 with LPD75. This is the LZEB2025 case with 75 % of the lighting power density of 90.1-2004.
- LZEB 2025 + Plug/process 25. This is the LZEB 2025 with a 25 % reduction in plug loads.

The results were presented in terms of the percent of buildings that achieved Net Zero Site Energy use. It was found that 5 % of the buildings achieved this level under the Base Case with PV scenario, 23 % under the LZEB 2005 scenario, and 60 – 70 % under the other scenarios. These results suggest that it is possible to achieve a Net Zero Energy Building for some situations.

The average net site energy savings were 44 % for the Base Case with PV scenario, 82 % with LZEB 2005, and about 140 % under the other scenarios. These results show that significant savings in site energy are achievable, but that PV is necessary to generate electricity. Without PV, aggressive strategies are needed to achieve 50 % to 70% energy reductions.

The results by sector show that the highest percentage of floor area that Net Zero Site Energy use under LZEB 2005 are warehouses, strip malls, laboratories, retail, service, and educational facilities. The lowest are food service, office buildings, and lodging.

The overall conclusions from this study are that:

- Net Zero Site Energy use is technically feasible.
- Efficiency is as important in reducing energy as PV is in production, and may be more important when the cost associated with the PV system is considered.
- It is more difficult to reach Net Zero Site Energy in a heating climate than a cooling climate.
- Aggregate energy reduction potential is greatest for warehouses, office, and educational facilities.
- Aggregate energy reduction potential is medium for retail, public assembly, strip malls, service, religious, lodging, and food service facilities.
- Aggregate energy reduction potential is lowest for health care, enclosed malls, and laboratories.
- The building sectors with the highest technical potential to reduce energy use are not necessarily the sectors with the highest impact on aggregate energy use.
- The goal of a 50 % to 70% Approach to Net Zero Energy is feasible. There are no apparent technological barriers to achieving the desired energy reductions.

Appendix 3: Current High Performance Buildings

In the last several years, a number of buildings have been constructed that approach or meet the goal of 50 % or less energy consumption. Although they are significant in what they have achieved, they represent a very small proportion of the 6 million or so US building stock. Some of these buildings have been carefully evaluated and monitored by outside groups, while for others the energy performance is self-reported. The important output from the reports on these buildings is a delineation of the techniques that were most successful in reducing energy use and identification of those that need to be improved or replaced. The studies are summarized below along with a summary of the measures employed.

NREL/DOE Case Studies

Six buildings in which NREL worked with the owner in either designing or modifying an existing design and then monitoring the building performance have been intensively studied. A summary of the results is given in “Lessons Learned from Case Studies of Six High-Performance Buildings”, by Torcellini, et al., June 2006. A detailed description of the design process and the results for each building is available from the websites listed in the References.

For each of the buildings a “Baseline” built to an ASHRAE Standard 90.1 (the base was not always the same version) was simulated and a large number of alternatives examined. The building was then constructed or modified based on the simulation results. The performance of the “As Built” building was determined from monitoring the building over a one or two year period and combined with a calibrated model.

The performance results are summarized in Table 3.1. The “net” values account for the PV electric production.

Table 3.1. Summary of NREL/DOE Case Studies

Type	Floor Area (ft ²)	Actual Site Use (kBtu/ft ²)	Net Site Use (kBtu/ft ²)	PV Gen. (%)	Site Energy Savings (%)	Net Source Savings (%)
Building						
Lewis Center for Environmental Studies, OH (Classroom/office)	34,000	29.8	16.4	45	47	79
Zion National Park Visitor Center, UT	42,366	27.0	24.7	8.5	62	65
Cambria Office Building, PA	31,000	36.8	36.0	2.7	40	42
Chesapeake Bay Foundation, MD (Visitor Center)	13,000	40.2	39.9	0.7	25	22
NREL Thermal Test	8,800	28.5	28.5	0	42	45

Facility, CO (Lab & Office)						
Big Horn Home Improvement Center, CO (Office/warehouse)	10,000	39.5	39.5	2.3	35	54

A number of observations relevant to the development of the 50 % to 70% Guides are relevant.

- The “site energy savings” shows that annual energy reductions of up to 62 % are possible, not accounting for energy generation by PV. When the generation of electricity is included, the net source (and net site) energy savings are increased.
- Site energy reductions can approach 50 % through aggressive design approaches, but only one of the buildings actually exceeded a 50 % reduction. Achieving a 50 % reduction without electrical generation will be difficult.
- A number of technologies were employed that yielded significant energy reductions. Some of the commonly employed techniques (which were not used in all buildings) were:
 - Illumination: The building was designed to utilize daylighting and the lighting systems was designed and controlled in combination with high efficiency lighting. The design illumination power density was 0.75 W/ft² or less
 - Envelope: High levels of wall and window insulation. Low e double or triple glazed windows with low SHGC
 - Circulation and ventilation: VAV systems with variable capacity fans, under floor air distribution system, displacement ventilation, ERVs controlled in combination with economizers.
 - PV system that was tied to the grid and/or with battery storage.
 - Equipment: GSHP with extended range for heating and cooling
 - Radiant floor heating
- There were a number of climate-specific techniques, such as natural ventilation, evaporative cooling, and passive solar; that would not be applicable in all climates or for all buildings.

An important aspect of the study of these buildings was the lessons learned about their operation and performance. The main observations are given below. The Scoping Study Committee emphasizes that this is a small data set.

- These low energy buildings do not operate as designed. They use more energy and produce less from PV than is predicted. Some of the reasons are poor controls, the design engineers were overly optimistic about occupant behavior and acceptance of energy reduction measures, the energy savings due to daylighting were less than predicted, the plug loads were greater than expected, the building insulation was not as good as expected, and the PV systems performed poorer than predicted.
- The daylighting and electrical illumination systems need an integrated control system.
- The economizer and ERV need an integrated control system.
- Evaporative cooling can be used to advantage in dry climates
- Natural ventilation systems work but require careful design
- Electrical demand can be reduced using an integrated demand control system.

ASHRAE Technology Award buildings

Many of the ASHRAE Technology Award buildings are high performance buildings, and have been reported in the ASHRAE Journal. There is considerably less information available on the equipment, modifications, and performance than the DOE/NREL buildings and the performance is self-reported. Although the actual energy use was measured the baseline performance was not determined and the savings are an estimate. The main emphasis in the design appears to be on the cost savings. A number of the Technology Award buildings are given in Table 3.2.

Table 3.2. Summary of ASHRAE Technology Award Buildings

Building Type	Floor area (ft ²)	Location	Energy Use (kBtu/ft ²)	Energy Savings (%)
Office	350,000	CA		50
Airport	379,000	NY	146	20
Civic Center	330,000	CA	74	50
Supermarket	200,000	OK	66	23
Retail	45,000	Canada	50	68
Office & manufacture	85,300	PA		41

These buildings are generally considerably larger than those of the DOE/NREL study and also represent a broader range of commercial buildings. They demonstrate, too, that it is possible to design a high performance building using current technology. However, even with the reported percent energy savings the energy use per unit floor area is higher than the DOE/NREL buildings. Some of the technologies that were common to the ASHRAE Technology Award buildings are listed below.

- Equipment:
 - An economizer to use outdoor air for “free” cooling
 - Variable capacity pumps, fans, chillers using VFD, multi-speed, and incremental capacity units
 - High efficiency chillers, cooling towers
- Waste heat recovery from refrigeration and AC equipment and between heating and cooling zones
- Ventilation: An ERV in which the ventilation air is processed separately.
- High efficiency lighting, with a power density less than 1 W/ft²
- An EMCS system for implementing control strategies, including demand management, optimization, and fault detection and diagnosis.

New Buildings Institute Website

The New Buildings Institute database was developed to show that buildings can reduce energy use by 50% in all climates, all common building uses, and in both new and retrofit construction. The list of projects was initially gleaned from the AIA, BetterBricks, CHPS, DOE, EERE, GGHC, LEED, and Natural Step databases. Each project was screened to determine whether it approached or met the threshold of 50% better than ASHRAE 90.1 – 2001. Often the savings were not given in reference to ASHRAE 90.1 specifically, but were defined as “better than a code minimum building”. Project savings estimates are self reported and based on a combination of modeling and

measured energy data to determine baseline annual energy use. Many of the projects include a review of the modeling by a third party.

A total of 83 buildings were identified; these do include the DOE/NREL buildings and some of the ASHRAE Technology Award buildings. Projects are predominately office, education and medical/lab buildings, but there are examples of housing, retail, assembly and warehouse buildings as well. Projects were identified in most areas of the country, but the largest numbers are in the North East and West coast regions. However, there are eight buildings in the heavy air-conditioning area of the South East, and seven buildings in the winter-dominated Mid-west. The median values for size and performance on a per unit floor area basis for the buildings that met the criteria are given in Table 3.3.

Table 3.3 Performance for Buildings in the NBI database

Building Type	Floor Area (ft ²)	Energy Use (kBtu/ft ²)	Number of Buildings
Office	143,000	44.1	
Medical/Lab	115,000	159.0	
Residential	170,000	41.0	
Higher Education	47,000	30.1	
Flex	43,000	34.6	
K-12	112,000	26.6	
Assembly	23,500	25.0	
Retail	10,500	46.8	
Interpretive Center	11,200	35.4	
Warehouse	43,000	4.4	

A number of technologies commonly used in the buildings were identified. The technologies and an indication of their use in these buildings is

- Controls – nearly 90 % of the buildings had a supervisory control system
- Daylighting - employed in over 90 % of the buildings. Typically this included controlling electric lighting through dimming or step relay controls, with many systems including occupancy control.
- Increased ventilation – in over 50 %
- Natural ventilation – in almost 40 %
- Heat recovery – in about 30 %
- PV systems – in about 30 %
- Advanced glazing systems – about 25 %, and was the most often mentioned shell element.
- Underfloor air distribution and displacement ventilation – about 20 %
- Ground source heat pumps – about 20 %
- High efficiency equipment for the mechanical systems, with variable frequency drives in about 15 %, although this number is probably significantly under-reported.

The overall conclusion from an examination of these high performance buildings is that is possible to achieve a 50 approach to net zero energy use using technology currently available. However, it is not easy. It requires a careful and integrated design together with the incorporation of many modern energy reduction techniques.

Appendix 4: DOE Report On Impact Of Technologies To Reduce Building Energy

Two reports prepared for the DOE Department of Building Technologies in July, 2002, provides a perspective on energy use in buildings. One report evaluated HVAC use and the second evaluated illumination energy use, and both attempted to identify areas in which significant improvements were possible.

For commercial buildings in the US, the total primary (source) energy use is 14.7 quads. Of this, the HVAC systems use is 4.6 quads, illumination use is 3.8 quads, water heating use is 1.2 quads, office equipment use is 1.2 quads, and everything else adds to 3.9 quads.

The report found that the breakdown of HVAC primary (source) energy use is about evenly divided between three categories:

Cooling Energy 1.4 quads
 Heating Energy 1.7 quads
 Parasitic Energy (fans, etc.) 1.5 quads

(The Scoping Committee believes that the relative amount of parasitic energy use is too high)

In the study, 55 HVAC technologies were listed and 15 were then selected as to their potential for energy reductions. The technologies were categorized as “New,” “Advanced,” or “Current.” The estimated potential savings for these 15 technologies and the projected payback periods are given in Table 4.

Table 4 Impact of Selected HVAC Technologies

Technology	Status	Savings (quads)	Payback (years)
Radiant ceiling Heating/Cooling	Current	0.6	0
Energy Recovery Ventilators	Current	0.55	2
Dedicated outdoor air systems	Current	0.45	0
System/component diagnostics	New	0.45	
Variable refrigerant volume flow	Current	0.3	Variable
Improved duct sealing	Current	0.23	10
Adaptive & fuzzy control	New	0.23	
Displacement ventilation	Current	0.2	7
Novel cool storage	Current	0.03 – 0.2	Variable
Liquid desiccant air conditioning	Advanced	0.06 – 0.2	
Higher efficiency motors (ECPM)	Current	0.15	3
Smaller centrifugal compressors	Advanced	0.15	
Microchannel heat exchangers	New	0.11	6
Heat pumps for cold climates	Advanced	0.1	
Micro-environment control	Current	0.07	Long

The common themes identified that would reduce HVAC energy use are

- Separate treatment of ventilation and internal loads
- Improved delivery of conditioning where needed
- Improved part load performance

The Scoping Committee noted that the report did not address basic improvements in system efficiency, where there is appreciable potential.

Illumination energy use and Technology Options were also evaluated. Of the commercial lighting use of 4.2 Quads of primary energy use, fluorescent lamps account for 60 % of the total, incandescent 30 %, and HID 10 %. The authors concluded that the greatest potential energy reductions for fluorescent use for the near-future would occur with the development of small diameter lamps and dimmable ballasts. Other Technology Options were thought to take a longer time to achieve.

The Scoping Committee disagrees with the conclusion that small diameter lamps would significantly decrease energy use. This statement appears to be predicated on the assumption that T5 lamps are more efficacious than T8 lamps, which is not correct. It may be that the fixture efficiency can be improved with a smaller source. The Scoping Committee also believes that dimming ballasts are not inherently more energy efficient.

The Scoping Committee believes that the greatest potential energy reductions for lighting are (a) introduction of new lighting design criteria (e.g., based upon brightness rather than luminance or illuminance, which may be a long slow process that is unlikely to have significant impact in a few years), (b) local on-off controls designed to match light operation with occupancy (e.g., motion sensors), (c) on-off controls where daylight can be used to displace electric light and (d) lighting systems that provide non-uniform light levels in spaces that are consistent with the illumination needs.

References:

National Energy Modeling System for AEO 2005, Feb. 2005; BTS/A.D. Little, Energy Consumption Characteristics of Commercial Building HVAC Systems:

Volume I National Lighting Inventory and Energy Consumption Estimate, Sept, 2002

Volume II: Thermal Distribution, Auxiliary Equipment, and Ventilation, Oct. 1999

Volume III Energy Savings Potential, July, 2002

Appendix 5: Issues in Lighting

A number of issues were raised during the preparation of this report and a number of general statements were made that complemented the evaluation of the different measures. These issues are presented in this appendix.

Electric Lighting

Illumination inside buildings is a complex subject. Significant lighting energy savings can be achieved by addressing both lighting technology and illumination system design. Properly designed and implemented, it is possible to significantly reduce the connected electric lighting load.

The three important areas of illumination technology and design are:

1. Layers of light should be used more commonly whereby low (brightness based) general illumination is provided in a space and task and accent lighting are added to locations where higher light levels are required. To reach this goal: (1) lighting recommendations for general illumination where critical visual tasks are *not* performed should be based upon brightness, and (2) luminous efficacy should only be used to characterize non-directional general illumination, not task, lighting systems.
2. Daylight offers significant potential energy savings. However, sensing and control systems need to become more robust and less expensive before these savings can be realized.
3. Motion (occupant) sensors should be widely implemented. These are a robust technology that can be implemented without significant expense.

Layers of Light - Brightness based lighting recommendations

Current light level recommendations are based upon long-standing, assumptions about the visual system (CIE, 1931). The photopic luminous efficiency function is based upon the achromatic spectral sensitivity of human central vision to electromagnetic radiation. However, it does not properly represent brightness perception. Light sources of different spectral power distributions but producing the same measured luminance will subjectively appear to produce different levels of brightness. By taking advantage of this fact, it is possible to reduce ambient light levels without necessarily compromising impressions of room brightness.

In general, as light levels increase visual performance increases, but at an ever diminishing rate (Rea and Ouellette, 1991). Thus, visual performance is relatively unaffected by changes in light level over the range commonly found in architectural spaces, even for older workers up to age 50 years. Over the past 35 years recommended light levels have been cut by half or two-thirds without apparent loss in worker productivity. However, reducing light levels *will* strongly reduce visual performance for very small or low contrast tasks. Therefore high light levels need to be maintained in critical task areas (e.g., surgery) or where the visual task is inherently difficult to see (e.g., repairing watches). For “typical” reading materials, light levels can be reduced without significant reductions in visual performance.

Figure 1 shows the range of visual performance expected for “typical” reading materials and for “typical” visual capabilities of the work force up to age 50 years. Ambient light levels could probably be reduced up to 25% without noticeable effects on visual performance in non-critical areas or where the visual tasks are inherently easy to see (e.g. walking throughout an office space), Even though task lighting levels could be reduced below current recommendations without seriously affecting visual performance, there is probably little reason to do so in areas where visual tasks are commonly performed. If the illumination system delivers illumination only to the task

area, high light levels (500 lx or higher) can be maintained without significant impact on the electrical load because visual task areas are small relative to the entire building space.

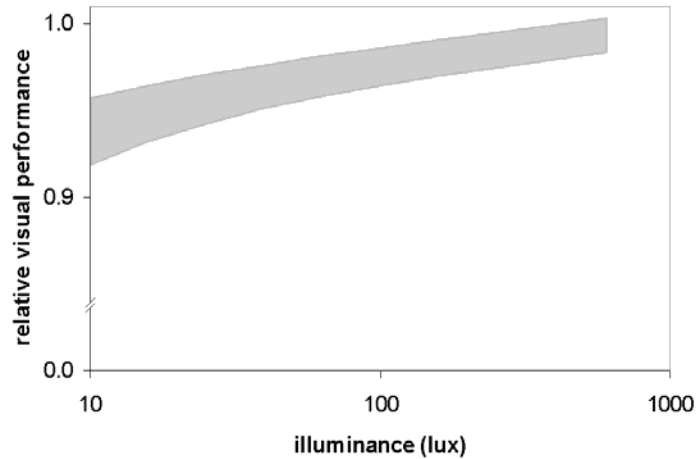


Figure 1. Levels of visual performance for reading printed material on white paper illuminated by white light for people between 20 and 50 years of age. (Based upon Rea and Ouellette, 1991, with figure from Figueiro et al., 2006.)

Attempts to reduce ambient light levels in the past have been met with complaints that perceived reductions in room brightness make office and work spaces appear “gloomy”. Current lighting recommendations are not explicitly based upon perceived brightness. However, (a) the widespread use of self-luminous electronic displays, (b) the insensitivity of visual performance to reductions in illuminance and (c) inexpensive, energy efficient, and widely available task lighting make it possible to set ambient lighting standards based upon perceived brightness rather than visual performance. Lighting recommendations based upon a brightness criterion could reduce connected lighting loads by 25 to 50% without affecting the perceived brightness of architectural spaces.

Changing lighting standards will take time, but the current interest on reducing energy use in lighting can accelerate the process. Basing standards on perceived brightness can be done without compromising safety or lowering lighting levels in task areas where visual performance is important.

Further, there is a relationship between the correlated color temperature (CCT) of the illuminant and relative brightness for the same light level. Light from a cool, 6000 K lamp can, depending on the lamps spectral power distribution, appear 40% brighter than that from a warm, 3000 K lamp for the same light level reading. Thus, lighting loads for ambient lighting (again, not for task lighting) could be reduced by about 40% while maintaining constant brightness if a lighting system utilizing 6000 K lamps replaced one using 3000 K lamps.

Application efficacy: Luminous efficacy (lm/W) is often used to compare lighting systems. It is assumed that those lighting systems that produce greater lumens (lm) per watt (W) are more “energy efficient.” This is generally true for lighting systems that emit diffuse, ambient light throughout an architectural space (e.g., direct/indirect suspended fluorescent lighting systems for general lighting), but it is *not* true for directional light sources (e.g., track halogen lighting for illuminating a picture on the wall). Since flux, measured in lumens, is measured without regard to direction, it is not possible to meaningfully compare diffuse and directional lighting systems in terms of their energy efficiency. Indeed, luminous efficacy can significantly misrepresent the effectiveness of directional lighting systems.

Application efficacy (Rea and Bullough, 2001) is based upon the notion that the most efficient lighting system is one that delivers light to the desired location and *only* to that location at the lowest electrical power; light going to other locations is simply wasted, reducing the efficacy of the system. Figure 3 illustrates how the concept of application efficacy could be used in specifying down lighting for a kitchen sink.

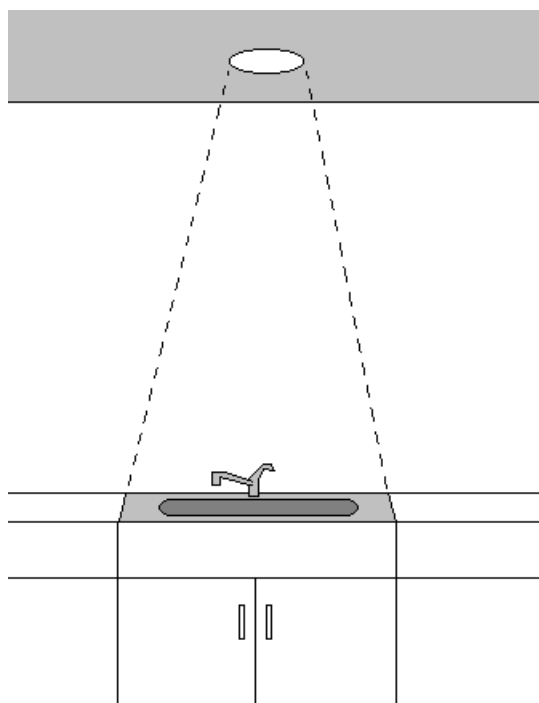


Figure 2. Illustration of application efficacy in lighting for a kitchen sink (Figure from Bullough and Rea, 2004.)

The application efficacy (AE) is measured in terms of luminous intensity (cd) per watt (W), where intensity is defined as the flux (lm) directed within the solid angle (ω) defined by the area (A) of the object to be illuminated (e.g., a picture on the wall) and the squared distance (d) between the object and the light source:

$$AE = cd/W = (lm/\omega)/W = (lm d^2/A)/W \quad (1)$$

Luminous intensity, based upon photopic luminous efficiency, is used in the formulation of AE because, generally, visual performance and seeing fine details *is* more important than brightness for directional lighting systems.

The application efficacy of directional lighting systems should be evaluated using equation 1, *not* in terms of their luminous efficacy (lm/W) as currently done. Adding task lighting will increase lighting load, but this will be offset by reducing ambient lighting levels through brightness-based lighting recommendations. Assuming that 20% of the floor area is devoted to “visual tasks” that need to be illuminated the increase in lighting load will be modest and produce good task visibility.

Lighting controls

Lighting controls have the potential to reduce connected load and energy use without negatively impacting performance (DOE report). Motion sensors can be used throughout a building, and offer a practical solution to effectively reduce lighting energy in unoccupied zones in buildings. Photosensor applications on the other hand depend heavily on the type of space. They are most

applicable in in skylighted areas and have a much smaller potential in areas with illumination supplemented by side lighting (i.e., windows) due to limited access to daylight (often less than 20% of the floor space), higher initial cost for installation and commissioning, and higher costs and lower reliability when used in conjunction with existing fluorescent dimming systems.

Motion sensors: Illuminating architectural spaces when they are unoccupied is almost always a waste of lighting energy, unless security is an issue. It is important to be able turn lights off in unoccupied spaces. Motion sensor technologies are both inexpensive, widely available, simple to install and perform well in applications (DOE report). Currently, they are utilized in new construction but not as well in existing buildings. Wide spread usage of motion sensors could reduce lighting energy loads by as much as 30% in some building types such as offices.

Photosensors: Photosensors that control the operation of electric lighting systems in response to daylight have been under development for 25 years, but are still not a robust technology. They work best with skylights because daylight and electric lights in the ceiling produce nearly the same spatial distribution of light within the space. Photosensors can readily be used to substitute daylight from skylights with electric lighting. Photosensors used in conjunction with side lighting (i.e., windows) are at present more difficult to commission than skylight applications. If the sensors are not calibrated and commissioned properly it is difficult to achieve lighting energy savings. Establishing a functional relationship for substituting electric light from the ceiling with daylight from windows without sudden changes in illumination is the biggest challenge to overcome.

Recent self-commissioning laboratory prototypes have been developed and shown to work quite well in a few demonstration projects, yielding 50% energy savings in daylit spaces (Lighting Research Center, 2004). A number of lighting controls companies offer photosensor-based controls that have been demonstrated to work properly when commissioned properly. Assuming that, on average, daylight can be effective for 40% the floor space in buildings, and that half the energy can be saved in these spaces, then the potential for daylight offsetting electric light can be responsible for a 20% reduction in electric lighting load.

Photosensors are often closely associated with dimming fluorescent lighting systems since smooth changes in electric light levels are most compatible with occupant satisfaction and acceptance. The initial cost of fluorescent lighting dimming systems is greater than that for switching systems, although the costs are decreasing. Interchangeable components in lighting systems are not always compatible in dimming systems, although they may be suitable for lighting systems that simply switch. Whereas frequent on-off switching in response to daylight has been found to cause annoyance among occupants (Boyce, 1984), infrequent switching and switching only after high daylight levels are present will certainly mitigate complaints, but may reduce energy savings. Photosensors appear to have a good, but presently unrealized, potential for energy savings. Widespread energy savings in sidelighted spaces will be achieved if the cost, commissioning, and compatibility issues are addressed.

Expected energy savings

The energy savings from advanced lighting system components are estimated as:

1. Task /Ambient Lighting
 - Brightness based ambient lighting- up to 40%
 - Task lighting using Application Efficacy reduces the savings by up to 20%.
2. Occupancy
 - Motion sensors, for typical office occupancy loads –up to 30 %.
3. Daylight
 - Combined with dimming/switching – up to 20 %

Applying all of these measures in appropriate applications could yield up to a reduction of 60 % in lighting energy use during daytime hours. Lighting represents about 30% of the electric use in a building (USDOE, 2002), and about 20 % of the total energy use. New lighting design criteria and controls could reduce building energy use up to 20 %.

References

- Alman, D.H., J. Illum. Eng. Soc 7(1) 55-62, 1977
- Bierman, A, US patent 6,583,573, 2003.
- Boyce, P.R., Lighting control: The user's point of view, Lighting Controls, Proceedings of the CEA/DBR Symposium, Ottawa, Rea, M.S. (ed.) 69-85, 1984.
- Bullough, J.D, and Rea, M.S., Lighting and Lighting Systems, The Optics Encyclopedia, Vol. 2, (Brown, T.G., Creath, K, Kogelnik, H., Kriss, M.A., Schmit, J., and Weber, M.J. (eds), Wiley-VCH, Weinheim, 1323-1336, 2004.
- Dillon , R.F., Pasini, I.C., and Rea, M.S., Survey of visual contrast in office forms, Commission Internationale de l'Eclairage (CIE) Proceedings, Venice, 74-77, 1987.
- Lighting Research Center, Daylight Dividends,
<http://www.lrc.rpi.edu/programs/daylightdividends/>), 2004\
- Lighting Research Center, Reducing Barriers to Use of High Efficiency Lighting Systems (<http://www.lrc.rpi.edu/researchtopics/reducingBarriers/resources.asp>), 2004
- Rea and Ouellette, Ltg. Res. Tech., 23(3), 135-144, 1991.
- Rea, M.S. and Bullough, J.D., Application efficacy, J. Illum. Eng. Soc., 73-96, 2001
- Smith and Rea, Commission Internationale de l'Eclairage (CIE) Proceedings, Kyoto, CIE, 207-211, 1980.
- U.S. Department of Energy (DOE), U.S. Lighting Market Characterization, Volume 1: National Lighting Inventory and Energy Consumption Estimate, Prepared by Navigant Consultants, 2002.

Daylighting

An aggressive design goal for a well-designed daylighting system would be to impact 80% of net floor area with a design that saves 50 – 70 % of lighting energy during typical commercial occupancy schedules. Such a system would reduce whole building lighting use by up to 40-60%.

Existing daylighting systems typically can provide adequate daylight to offset electric lighting on the floor area that is about 1 to 1.5 times the ceiling height from the envelope. This is a 10-15 foot deep band around the perimeter of a building, with the fractional floor area dependent on the footprint of the building. For example, a building with a 40,000 ft² square floor plan will allow only a small fraction (about 20 %) of the floor to be daylighted via windows. Daylighting is most easily achieved in spaces where sun control is not a problem, such as north-facing or shaded facades. On facades where there is significant solar gain the resource is much greater but inappropriate use of shading systems can significantly reduce the savings potential. Introducing daylight via overhead skylights is an alternate approach that allows single story buildings to be fully daylighted, and the large fraction of the building stock that is low rise buildings lend themselves to this technology. Approximately 50% of typical building stock can achieve a high level of daylighted floor space. (Torcellini, et al., “Lessons Learned from Case Studies of Six High-Performance Buildings”, June 2006)

Most commercial buildings have occupancies during daytime that follow the availability of sunlight. For most U.S. latitudes the fraction of the working year that occurs during daytime hours for most commercial building types is very high (e.g. 80-90%). The fraction of the lighting need that can be met over those hours varies with external conditions (location, climate, site conditions, and orientation), glazing and fenestration conditions, internal room conditions, and lighting design strategy and illuminance requirements. Daylight is most commonly used to displace ambient lighting assuming that task lighting will be used by occupants but it can work well for overall lighting in retail and office applications as well. Daylight can best be associated with a space type as distinct from a building type, e.g. an entrance lobby in virtually any building type could be daylighted. With an aggressive daylighting strategy combined with electric lighting control, it may be feasible to reduce lighting energy use by 50-60% in sidelighted spaces and by 60-80% in skylighted spaces. These savings are best captured with a system using daylight sensors and dimming electronic ballasts.

Light Emitting Diodes (LEDs)

The use of LEDs to provide lighting is a subject of much current interest. The Scoping Study Committee believes that LEDs are an important technology and will be more so in the future, but that commercial products for general illumination will not be developed for several years. The Scoping Study Committee recommends that the Guide development committee not include LEDs as measures that can have an impact by 2010.

The status of the field is that there are a variety of white LED products available on the market including desk and under-cabinet lights, flashlights, head lamps, outdoor pathway lights, and decorative string lights. LEDs are continually finding more niche applications. For most illumination applications, however, white LEDs cannot yet compete with traditional light sources on the basis of performance or cost. The best white LEDs are similar in efficiency to compact fluorescent lights (CFLs), but most of the white LEDs currently available in consumer products are only marginally more efficient than incandescent lamps. The best white LEDs available today can produce about 45-50 lumens per watt (lpw). For comparison, incandescent lamps typically produce 12-15 lpw and CFLs produce at least 50 lpw. Many LED products use only a small amount of energy, and therefore may appear energy efficient, but they often have very low light output.

This is an active research area, but there are many application issues that have not yet been solved. One of the biggest is that system efficacy is not the same as chip efficacy. System efficacy is much lower than the numbers for chip efficacy that are being promulgated. Standard testing procedures and specification guidelines have not been developed. System life is still unknown for nearly every LED product due to unpredictable heat dissipation in the application. Finally, conventional technologies are also improving in efficiency may continue to be more effective in reducing lighting energy.