Using Leed® to Facilitate The Eisa Goal of Zero Fossil Fuel Use in New Federal Buildings*

Daniel L. Briller, P.E., LEED® AP
Booz Allen Hamilton

ABSTRACT

The Energy Independence and Security Act of 2007 (EISA) introduced numerous requirements to improve the energy and environmental performance of federal buildings. Section 433 of EISA established aggressive fossil fuel reduction targets for federal construction projects which exceed $2.5 million in total cost (adjusted annually for inflation) and/or require a U.S. General Services Administration (GSA) prospectus. These reductions, measured using the 2003 Commercial Buildings Energy Consumption Survey (CBECS) as the baseline, begin with 55% for projects initiated in Fiscal Year (FY) 2010 and increase stepwise to 100% for projects initiated in FY 2030.

The U.S. Green Building Council's (USGBC's) Leadership in Energy and Environmental Design (LEED®) system is the most widely used and widely accepted sustainable building rating system in the United States. It is a performance-based, quantifiable standard that evaluates the energy and environmental performance of buildings from a whole building, full lifecycle perspective. The project developer applies for points under a system of credits, which are grouped into six categories: Sustainable Sites (SS), Water Efficiency (WE), Energy and Atmosphere (EA), Materials and Resources (MR), Indoor Environmental Quality (IEQ), and Innovation in Design (ID). Based on the total points earned, buildings are certified at the Certified, Silver, Gold, or Platinum level.

This article will illustrate how integrative design strategies used to achieve high LEED® certification ratings at some federal buildings can

---

*Presented at the World Energy Engineering Congress, Washington, DC, November 5, 2009 simultaneously result in substantial fossil fuel consumption reductions consistent with the EISA objectives. Two specific strategies that exemplify this principle—under floor air distribution (UFAD) systems and daylighting—will be discussed in terms of their energy savings potential and lifecycle costs. In addition, the capability of renewable energy systems to supply the balance of the buildings' energy requirements (*i.e.,* after all energy efficiency measures have been implemented) will be assessed. Lastly, key technical and cost barriers to achieving near carbon neutrality at new federal buildings will be presented, and the potential for emerging technologies to address these shortfalls (including further research and development requirements) will be discussed. Actual case histories will be utilized to support the above-referenced evaluations.

INTRODUCTION

The Energy Independence and Security Act of 2007 (EISA) introduced numerous requirements to improve the energy and environmental performance of federal buildings. Section 433 of EISA established aggressive fossil fuel reduction targets for new construction and major renovation projects that meet one or both of the following criteria:

- Projects for which the administrator of the GSA is required to transmit a prospectus to Congress pursuant to 40 United States Code (U.S.C.) 3307 (prospectus projects).
- Projects with a total cost of $2.5 million or greater, adjusted annually for inflation.

Facility projects that meet these criteria are required to achieve the targets for reduction of fossil fuel consumption listed in Table 1. As noted in Table 1, the statute further states that the baseline against which fossil fuel usage reductions are to be measured is the 2003 CBECS value for a "similar" building.

The research and analysis described in this article was undertaken to accomplish the following objectives:

- Outline how the USGBC's LEED® system (and the integrative design practices it fosters) can play a critical role in helping federal

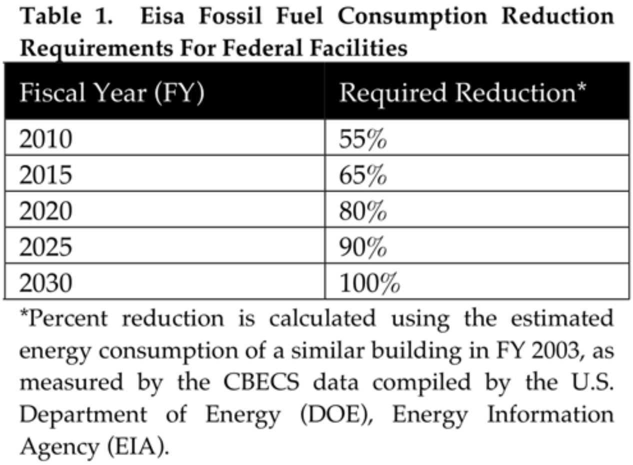


Table 1. Eisa Fossil Fuel Consumption Reduction Requirements For Federal Facilities

Fiscal Year (FY)	Required Reduction*
2010	55%
2015	65%
2020	80%
2025	90%
2030	100%

*Percent reduction is calculated using the estimated energy consumption of a similar building in FY 2003, as measured by the CBECS data compiled by the U.S. Department of Energy (DOE), Energy Information Agency (EIA).

facility managers identify strategies for new buildings to significantly reduce carbon emissions.

- Evaluate the energy demand reduction potential of two example strategies (under floor air distribution [UFAD] and daylighting) that a selection process based on LEED® indicates would be favorable to pursue at many buildings.

- Define the "gap" in fossil fuel reduction that must be addressed by renewable energy technologies in order to achieve net (or near net) zero energy status for the building, once UFAD and daylighting are incorporated.

- Assess the feasibility of renewable energy technologies, at the scale available today, to address the gap.

- Provide a cursory overview of several emerging technologies and the role they might serve in the process of both: (1) reducing energy consumption/demand and (2) increasing the supply of low- or zero-carbon energy on a scale suitable for typical federal buildings.

BACKGROUND

This section provides a brief introduction to net zero energy buildings (NZEBs) and discusses two of the limited number of case histories that have achieved this operating paradigm. A brief overview of the LEED® system is also presented.

Net Zero Energy Buildings (NZEBs)

The EISA requirements to drastically reduce fossil fuel usage in large federal new construction/major renovation projects were primarily motivated by present concerns about emissions of carbon dioxide (CO_2) and other greenhouse gases (GHGs), as well as the seemingly accelerating speed of global climate change. They are similar, although not identical, to voluntary goals previously proposed by the American Institute of Architects (AIA) and the World Business Council for Sustainable Development. The AIA program is often referred to as the "2030 Challenge for Buildings." The paradigm toward which these mandates are driving facility owners is what is generally called the "net zero energy building" (NZEB). There are many possible definitions, with subtle differences, of NZEBs. (For detailed definitions, refer to Appendix A in Torcellini [89].) In the broadest sense, the concept is that buildings of the future should produce enough energy from renewable sources at the facility (or on the facility site) to offset any of the following:

- Fossil fuels used on site (*e.g.*, coal-, fuel oil-, or oil-fired boilers or furnaces).
- Electricity obtained from the grid that was generated by off-site fossil fuel combustion sources (*e.g.*, coal-, fuel oil-, or natural gas-fired utility generating stations).

While the requirement directly stated by EISA is to reduce fossil fuel consumption in buildings, it is easily observed that pursuing NZEB status is one of the most obvious means by which this goal could be accomplished. Therefore, these concepts will be used interchangeably throughout the remainder of this article.

There are very few buildings in the United States (or in the world) that would currently conform to any definition of an NZEB. Two of the most-cited examples based in the U.S. are briefly described in the remainder of this section.

31 Tannery Project, Branchburg, New Jersey

The 31 Tannery Project is a 42,000-gross-square-foot (GSF) prefabricated, two-story commercial building. It contains office areas and a two-story open bay service shop and is used by a construction company as the company's administrative headquarters and vehicle maintenance facility. The facility's primary source of electricity is an array of building-integrated solar photovoltaic (BIPV) panels which occupy approximately 80% of the roof area. A high-performance, natural gas-fired boiler provides space heating to the office areas through a radiant floor heating system. Three rooftop air handlers with self-contained electric heating coils, air conditioning systems, and air-side enthalpy economizers provide the following:

- Space heating to the shop area.
- Ventilation and summer space cooling to the entire building.

A solar thermal array, occupying most of the remaining 20% of the roof, provides domestic hot water for sinks, showers, and the break room dishwasher. All building systems are managed by a direct digital control (DDC) system for optimum energy performance.

The project has achieved NZEB status by exporting, on an annual basis, more kilowatt-hours (kWh) of electricity back to the grid than the total energy (electricity and natural gas) consumed on site. The operators claim a net energy cost of -$1.11/GSF (*i.e.*, a net energy *revenue* of $1.11/GSF). In addition to the revenue, the building energy cost is $2.31/GSF less than a similar building constructed to code (an effective total savings of $3.42/GSF). In 2007, the facility was a net exporter of electricity to the grid for the months of May, June, July, August, and September. The facility has also achieved the maximum score under the federal ENERGY STAR® program (100 points).

IDEAS Z-Squared Building, San Jose, California

The IDEAS Z-squared facility is a 7,200-GSF restored 1960s-era concrete bank building now used as a design headquarters and experimental facility by an electrical engineering firm. The facility was able to achieve NZEB status through a combination of extensive energy efficiency measures and production of electricity from rooftop BIPV arrays. The facility's designers concentrated on minimizing energy use for lighting by employing:

- Maximum possible daylighting, using low-emissivity (low-e) window glazing, skylights, high-reflectance interior paints, and sun shades.

- Highly energy-efficient light fixtures to provide supplementary daytime and nighttime lighting.

Automatic shutoff controls are installed to shut off lighting fixtures when daylighting is sufficient for interior lighting and to shut off plug loads (*e.g.*, computers, copiers, plotters) during non-business hours. An electrically powered ground source heat pump (GSHP) provides primary space conditioning, with an electric radiant floor heating system for supplemental heating. The facility does not operate any fossil-fuel burning devices.

Building energy consumption is reported to be 60% less than the calculated American Society of Heating, Refrigerating, and Air-Conditioning Engineers (ASHRAE) 90.1-2007 Building Performance Rating for this facility. Currently, the facility does not purchase any electricity from the grid (*i.e.*, generates 100% of its required power); however, it does have a grid connection and exports surplus power to the grid. As a result, the facility is presently carbon-neutral. The owner is presently pursuing LEED® certification and claims that the facility will qualify at the LEED® Silver level.

Summary of Observations, 31 Tannery and Z-Squared Projects

When reviewing the information concerning these two case histories, several of the following cogent points are realized:

- Both facilities (in particular the Z-squared building) incorporate significant energy efficiency measures (*e.g.*, economizers, radiant floor heating, daylighting, energy management and control systems) to reduce the total energy that must be supplied from renewable energy sources in order to qualify as NZEBs.

- Both facilities rely primarily on solar BIPVs to generate electricity for on-site lighting, space conditioning, and plug loads.

- Both projects are relatively small in overall size (*i.e.*, based on interior GSF) and primarily contain office space.

- Both facilities are two stories or less in height, thus resulting in a high ratio of available rooftop area to occupied building volume. For this reason, solar BIPV and solar thermal technologies are capable of effectively supplying a large percentage of the buildings' total energy requirements.

- Both projects are located in states that provide favorable financial climates for renewable energy projects. California and New Jersey are "far and away" the Number 1 and Number 2 states in the nation in terms of public benefit funds set aside for renewable energy, with $4.15 billion and $637 million respectively (Haynes [41]). In addition, both states have "net metering" laws, which permit facilities that export electricity to take credit against subsequent invoiced costs for surplus kilowatt-hours (kWh) of electricity sold back to the grid.

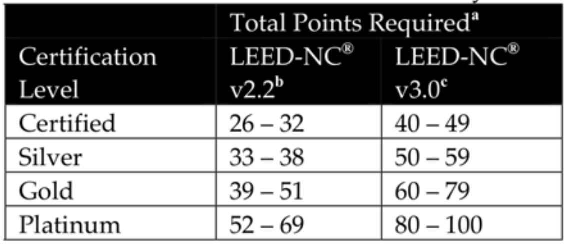
Leadership in Energy and Environmental Design (LEED®) System

The LEED® system is currently the most widely used and accepted sustainable building rating system in the U.S. It is a performance-based, quantifiable family of standards, all of which address facility energy and environmental design and performance from a whole building, life cycle perspective. The LEED® family comprises several LEED® rating systems, including New Construction (LEED-NC®); Existing Buildings, Operation and Maintenance (LEED-EB:O&M®); Commercial Interiors (LEED-CI®); and Core and Shell (LEED-C&S®).

A building must meet a set of seven minimum standards (prerequisites) to be eligible for potential LEED® certification. The project developer then applies for points under a system of credits, which are grouped into six environmental categories—SS, WE, EA, MR, IEQ, and ID—to achieve LEED® certification. A seventh category includes points for achieving specific requirements beyond those required for points in certain credit categories, or for initiatives not covered by specific credits presently included in the LEED® system. Based on the total points earned, buildings are certified at the Certified, Silver, Gold, or Platinum level. Table 2 presents the levels of certification for LEED-NC®, Version 2.2 (v2.2) and LEED-NC® v3.0. (LEED-NC® v3.0 recently took effect; however, LEED-NC® v2.2 levels are also shown, because many projects applying for certification under this system are still "in the pipeline").

Because this article primarily addresses federal projects that would be classified as new construction or major renovations, LEED-NC® will be the system referenced throughout the remaining discussion.

Table 2. Certification Levels For Leed-Nc® Systems



Certification Level	Total Points Required[a] LEED-NC® v2.2[b]	LEED-NC® v3.0[c]
Certified	26 – 32	40 – 49
Silver	33 – 38	50 – 59
Gold	39 – 51	60 – 79
Platinum	52 – 69	80 – 100

a. Tables A-1 and A-2 in Appendix A describe the specific LEED-NC® credits and the requirements for achieving points under those credits.
b. Total possible score under v2.2 is 69 points.
c. Total possible score under v3.0 is 100 points.

ANALYSIS

Figure 1 illustrates the pathway that building owners should follow in order to satisfy the EISA goals and reduce the carbon emissions associated with their buildings. There are four interim steps before one can approach the ultimate goal of reducing fossil fuel consumption by 100% for affected projects by 2030. The progression of these activities begins, in large part, with known, established technologies and measures (such as demand-side energy efficiency measures) and, at each new step, introduces technologies which potentially provide significant progress but also have an increasing degree of risk. The sequence also reinforces the well-known concept that minimizing energy demand and capturing energy that is normally wasted (*e.g.*, through heat recovery or economizers) will lower fossil fuel consumption much more than simply swapping out renewable sources for fossil fuel sources. Moreover, as will be discussed later in this article, renewable energy technologies (except for buildings in high sun- and wind-available climates), are unlikely to enable a building to become an NZEB without accompanying energy conservation and efficiency improvements.

Role of LEED® and Integrative Design Strategies

Projects that are pursuing LEED® certification generally have two objectives: (1) to become certified (*i.e.*, attain a minimum of 40 points under LEED-NC® v3.0) and (2) to achieve the highest level of certification practicable. Fulfilling both of these objectives requires that the project accumulate as many points as possible under the LEED® rating system. When one studies the system, it becomes evident that implementation of certain strategies and technologies will maximize accumulation of points and thus the overall LEED® score. Furthermore, the EISA requirement will drive federal building owners to implement technologies that simultaneously produce a high LEED® score and deeply decrease fossil fuel energy consumption.

Two of these technologies are UFAD and daylighting. As summarized in Appendix A, Tables A-1 and A-2, points can be earned from a high score in EA Credit 1, Optimize Energy Performance, as well as from other credits, particularly those in the MR and IEQ categories. In addition, it is important not to lose perspective and treat this process as solely an exercise to accumulate LEED® points or as merely a way to minimize fossil fuel energy consumption (though both are very important). As illustrated in Figures 2 and 3, for UFAD and daylighting respectively, the ultimate objective is to increase and maximize the net energy, environmental, economic, and other benefits inherent in application of the technologies. These obviously include reductions in carbon and air pollution emissions, as well as other benefits such as savings on utility bills, reduced churn costs, and higher worker productivity. (Churns are moves and reorganizations of a space.) As will be discussed later in this article, notwithstanding the energy and environmental advantages, these ancillary benefits often provide even greater motivation for pursuing technologies such as UFAD and daylighting. For example, since worker salaries and benefits often represent the largest component of operating costs at a facility, small gains in worker productivity can augment energy savings to produce short payback periods and high return on investment (ROI).

In the following sections of this article, more in-depth descriptions of UFAD and daylighting are provided, along with summaries of data from the literature indicating the magnitude of energy savings that has been realized at actual facilities or derived from simulation studies. Also included are discussion and results regarding energy simulation modeling of a test building that was performed specifically for this project to validate and supplement the literature findings.

Underfloor Air Distribution (UFAD)

Overview and Energy Savings Potential

UFAD originated from two companion technologies:

- Raised floor systems, which began being installed in computer rooms/data centers in the 1950s to accommodate necessary cabling.
- Displacement ventilation systems (used primarily in Europe, especially Scandinavian countries), which introduce air at relatively low volumes primarily to remove contaminants and latent heat from the ventilated space.

UFAD systems deliver ventilation and air conditioning from a plenum and/or duct located beneath a raised floor. The traditional overhead (OH) supply air ductwork, terminal boxes, and registers are not present, except for, in many cases, an OH return air collection plenum or ducts. The UFAD plenum beneath the raised floor may either be pressurized or equipped with terminal fans located at intervals beneath the floor. Air is delivered through grilles situated either within the floor or at/near the occupants' waist height (emerging from a raised duct or chase). The grilles are typically located near the occupants' work area (*e.g.*, at/under workstations) and are controllable, allowing users to modulate the airflow for optimum comfort. The grilles most commonly used are known as "swirl diffusers" and feature a twisted exit pathway for the air stream. Swirl diffusers, therefore, without any mechanical parts, aid in providing a degree of mixing within the occupied zone (*i.e.*, floor level to approximately six feet above the raised floor).

UFAD systems tend to outperform OH systems in spaces where ceiling height is uniform and not particularly high, and where flexibility to reconfigure the space on a frequent basis is advantageous (*e.g.*, office buildings and schools). UFAD is usually less advisable in spaces (1) with high ceilings (where natural stratification occurs even under well-mixed ambient conditions)*; (2) where odor control

---

*"Stratification," in this usage, refers to the undesirable migration of heating or cooling energy (depending on the season) and desirable migration of stale air to the air space above the occupied zone.

is critical; and (3) where tight tolerances on indoor air quality (IAQ) parameters are required. Thus, UFAD is often not suitable for gymnasiums, hospitals, "clean room" manufacturing environments, lobbies, and amphitheaters.

UFAD systems are often capable of producing significant energy savings, particularly during the cooling season, by virtue of the following characteristics:

- *Higher Supply Air Temperatures (Cooling Season).* Because of the natural stratification and buoyancy of warmed air, when operating in cooling mode, UFAD systems can deliver air at significantly higher temperatures than conventional overhead (OH) systems—on the order of 63 degrees Fahrenheit (°F) to 68°F, compared to approximately 55°F. (*OH systems are required to provide much cooler air, because they rely on mixing and conditioning most or all of the room air volume to achieve the design dry bulb temperature. Because in UFAD systems the temperature gap above the dew point reduces potential condensation on the cooling coils, additional dehumidification of the supply air is often required, and methods for accomplishing this are discussed later in this article*). Chiller energy savings, cooling tower fan energy savings, and air handler and fan terminal energy savings individually and in combination can be substantial. In addition, for buildings with UFAD that use the air-side economizer cycle, economizer operating hours are often increased, due to the higher return temperatures in recirculation air from the space. (Return temperature is typically used to control economizer operation.) These increased hours and associated energy savings may manifest in a couple of ways: (1) hours during which "free cooling" by outdoor air is sufficient to cool the building; and (2) hours when the economizer mixes cool outdoor air with return air to reduce the chiller load.

- *Significantly Less Air Mixing (Cooling and Heating Season).* In both cooling and heating seasons, UFAD systems are required to condition only approximately the lower six feet of the occupied space. In contrast, OH systems during the cooling season rely on mixing the conditioned air immediately below the ceiling registers with warmer air from the occupied zone (warmer not in the least part due to latent heat released by the occupants).

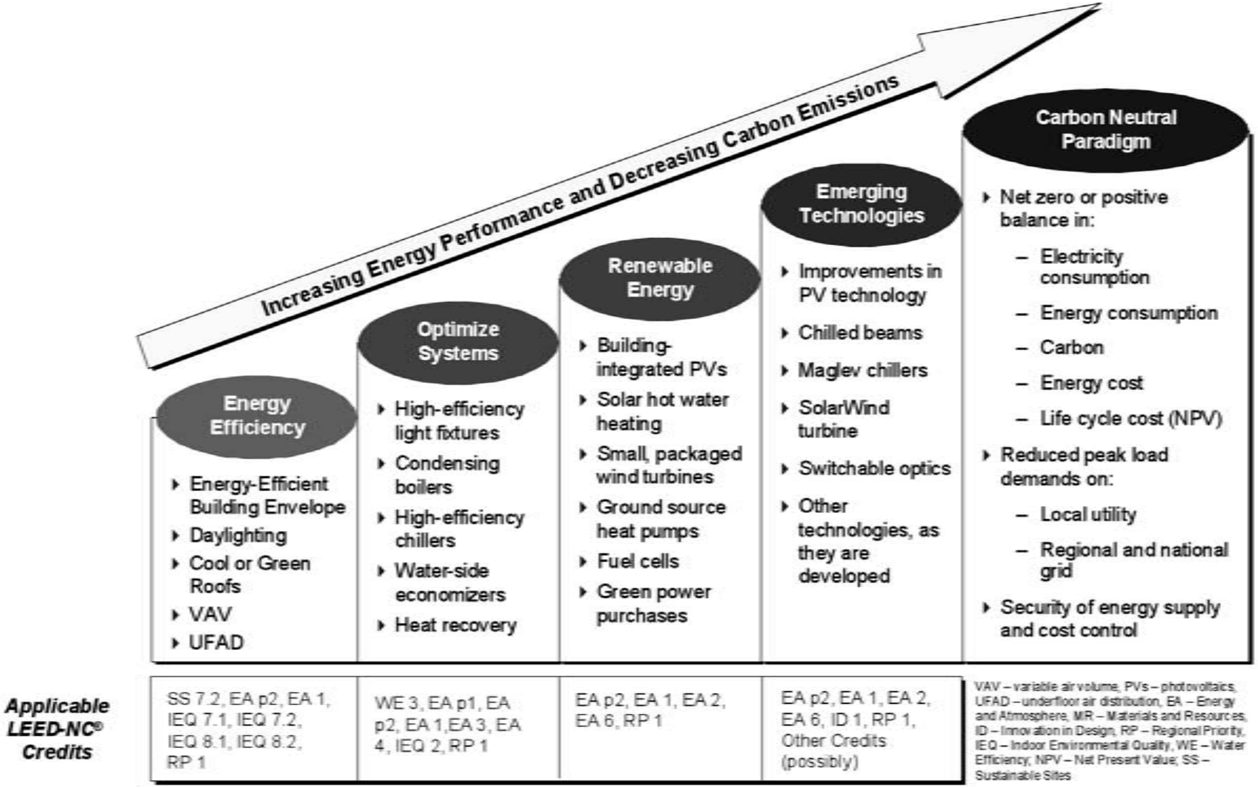


Figure 1. Pathway for Achieving Carbon Neutral Buildings

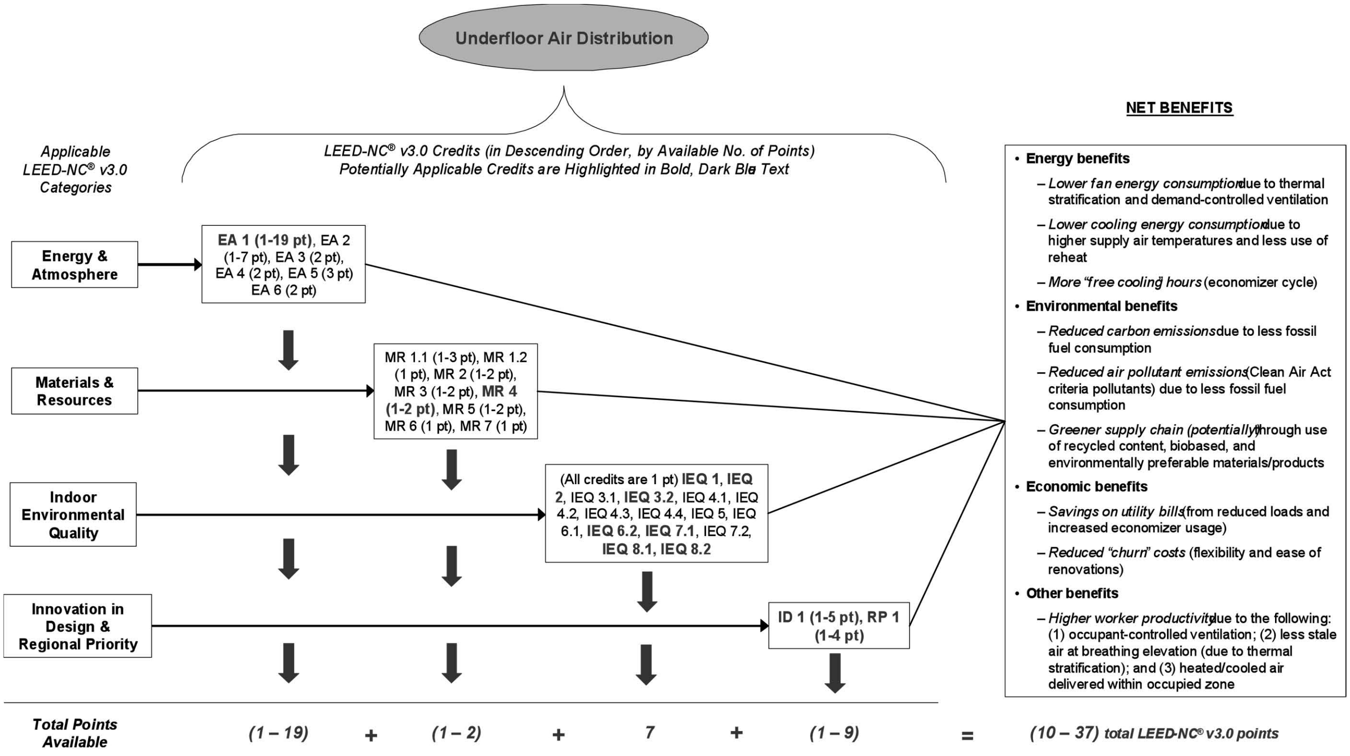
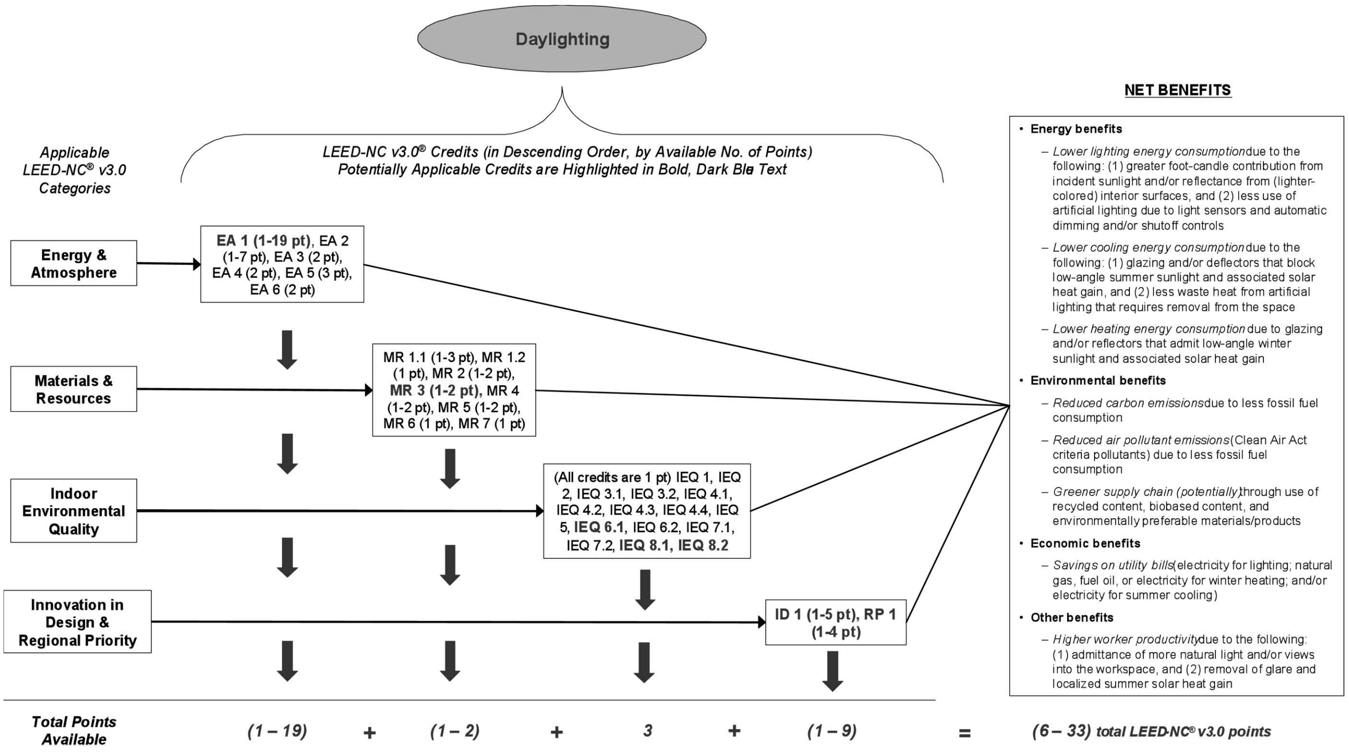


Figure 2. Decision Process for, and Benefits of, Underfloor Air Distribution Systems



NET BENEFITS

- **Energy benefits**
  - *Lower lighting energy consumption* due to the following: (1) greater foot-candle contribution from incident sunlight and/or reflectance from (lighter-colored) interior surfaces, and (2) less use of artificial lighting due to light sensors and automatic dimming and/or shutoff controls
  - *Lower cooling energy consumption* due to the following: (1) glazing and/or deflectors that block low-angle summer sunlight and associated solar heat gain, and (2) less waste heat from artificial lighting that requires removal from the space
  - *Lower heating energy consumption* due to glazing and/or reflectors that admit low-angle winter sunlight and associated solar heat gain
- **Environmental benefits**
  - *Reduced carbon emissions* due to less fossil fuel consumption
  - *Reduced air pollutant emissions* (Clean Air Act criteria pollutants) due to less fossil fuel consumption
  - *Greener supply chain (potentially)* through use of recycled content, biobased content, and environmentally preferable materials/products
- **Economic benefits**
  - *Savings on utility bills* (electricity for lighting; natural gas, fuel oil, or electricity for winter heating; and/or electricity for summer cooling)
- **Other benefits**
  - *Higher worker productivity* due to the following: (1) admittance of more natural light and/or views into the workspace, and (2) removal of glare and localized summer solar heat gain

Figure 3. Decision Process for, and Benefits of Daylighting

Assuming a 12- or 13-foot-high ceiling in a typical office building, approximately twice the air volume or more is being circulated by the OH system air handlers and/or terminal boxes. Thus, fan energy demand is usually noticeably lower for UFAD systems, while achieving an identical outcome (*i.e.*, providing sufficient heating and/or cooling to keep the occupants comfortable and meeting ASHRAE Standards 55 and 62.1, the thermal comfort and minimum ventilation standards, respectively).

- *Targeted Delivery of Warmer Air (Heating Season).* During heating season operations, the UFAD system is generally only required to supply sufficient heat to maintain comfortable conditions within the occupied zone. In contrast, heating provided by an OH system at ceiling level must be conveyed via air mixing (and against its natural gradient) down into the occupied space. Regardless of whether a UFAD or OH system is used, supplementary heating may still be required to prevent drafts and/or neutralize heat losses at the building perimeter.

Results of Literature Survey and Modeling

UFAD energy savings data collected from the literature (including operating facilities' case histories and modeling studies) are summarized in Figure 4 and detailed in Appendix B, Table B-1. To enhance this data set, additional energy simulation modeling was conducted, with the objective of parametrically assessing the potential contributions of UFAD and daylighting, respectively, with a case study of interest. The hypothetical test building chosen for modeling was a 10-story, 400,000-GSF office building (40,000 GSF/floor), located in Washington, DC. This selection was made in order to test the hypothesis of a zero or near zero carbon building in an environment where significant potential challenges toward meeting this goal may be present, including the following:

- Constrained site footprints that preclude a long East/West axis.

- Adjacent structures that might block available sunlight.

- Low ratio of roof area to total floor space, thus limiting renewable energy production (*e.g.*, solar panels).

- Significant fan and pumping energy requirements due to building size.

Additional key assumptions for the test building are presented in Appendix C, Tables C-1 and C-2. The eQUEST™ software, Version 3.6, which uses a DOE-2-derived hourly energy simulation engine, was utilized for the energy modeling. A Microsoft® Excel spreadsheet was also used to perform supplemental calculations and generate the graphical output displayed herein. A base case (as described in Appendix C) was developed, and four alternate scenarios (S1 through S4) were run. (Two additional scenarios, S5 and S6, were developed using the S4 results combined with different types of renewable energy sources.)

Scenario S1 represents the baseline case building, with UFAD substituted for a traditional OH heating, ventilation, and air conditioning (HVAC) system. As indicated in Figure 4, the computed total energy savings associated with UFAD for the test building compared with the base case was approximately 38%, generally conforming to the data from other operating buildings and modeling studies. The energy consumption reduction compared with the 2003 CBECS average for office buildings (approximately 53%) is also presented in Figure 4.

Additional Benefits and Limitations

Additional benefits (other than energy savings) of the UFAD technology have been well summarized in the literature and include the following:

- Increased flexibility and reduced churn costs.
- Improved occupant comfort and productivity.
- Savings in installation costs for ductwork, electrical systems, and mechanical systems.
- Savings in required floor slab-to floor slab height differential, which can in turn lead to lower quantity and cost of buildings materials (if the height is reduced) *or* provide increased window area for daylighting (if the height is not altered).
- Ease of maintenance and improved safety from working at ground level rather than in high-lifts.

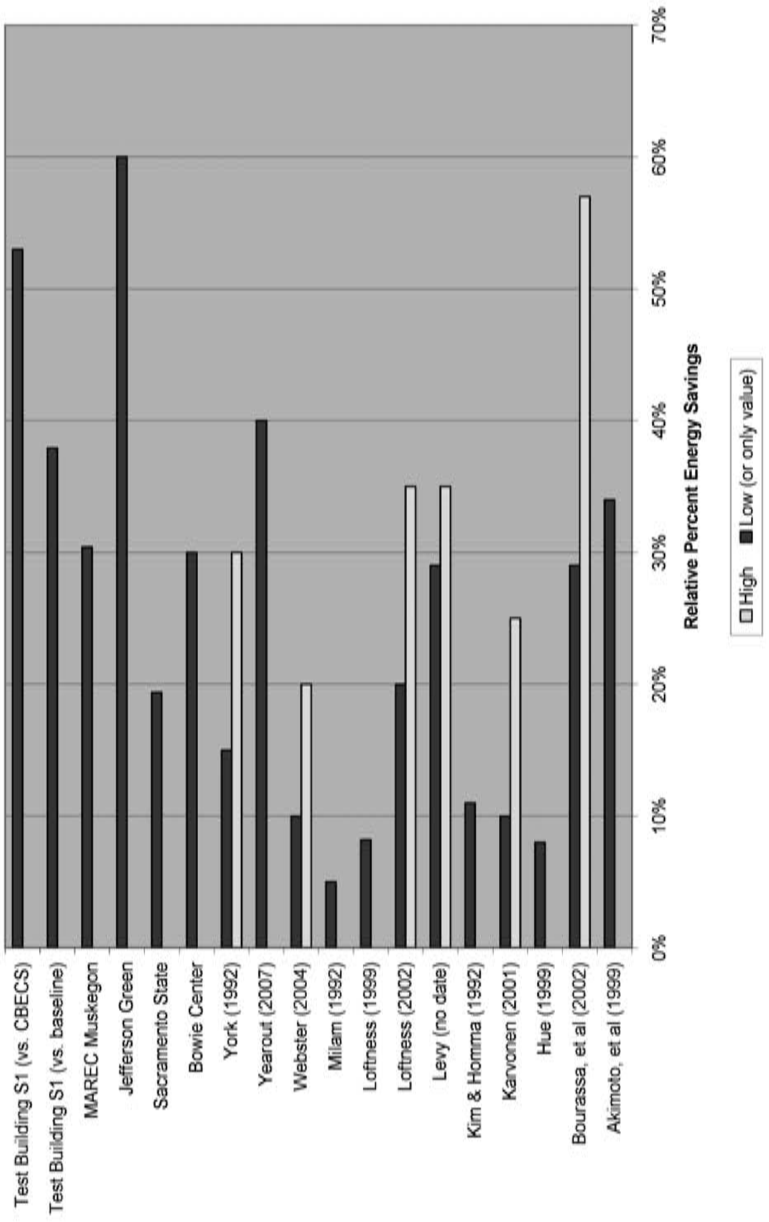


Figure 4. Energy Savings from UFAD

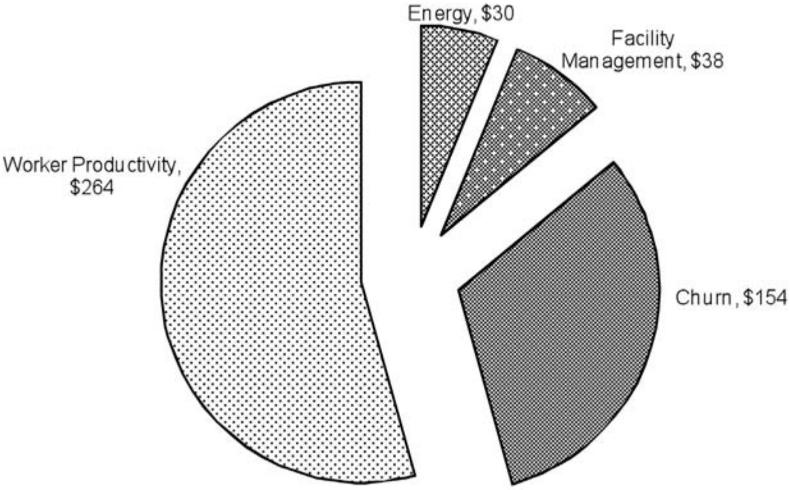
- Significant reductions in background noise when using a plenum-only configuration (*i.e.,* no terminal fans).
- Accelerated construction schedules (*e.g.,* a reported 10-15% time savings) due to less work at heights and/or use of plenums rather than extensive ductwork.
- Fewer dust emissions during churns that could affect personnel working in other areas of the building while renovation is underway.
- Less susceptibility to formation of dead pockets (*i.e.,* areas not adequately ventilated) and short-circuiting of airflow (thus leading to uncomfortable drafts) compared with OH systems, particularly in open-plan environments.

Limitations of UFAD include the following:

- Increased capital costs associated with the raised floor system.
- Fewer experienced contractors for new construction or retrofit applications.
- Potential air leakage if the carpet tile layout is not properly designed and implemented, which can result in two deleterious outcomes: (1) increased fan energy usage; and (2) formation of possible smoke migration conduits. (*Local fire code may ban or restrict UFAD systems on this basis.)*
- Potentially more frequent "cold feet" complaints, if insulated carpet tiles are not used.
- Leaking of adhesives used in the mastic layer and resultant IAQ problems. (*Use non-toxic adhesives where practicable.*)
- For buildings with dedicated, outdoor air systems (DOAS), limited dehumidification options. (*The most common and usually least costly option, side-stream mixing with return air, is naturally not possible for DOAS systems.*)

Notwithstanding the appreciable energy savings that UFAD systems can provide, energy efficiency will not usually be the only (or primary) rationale for employing this technology. Dramatic savings in worker productivity and savings during office churns can be realized. For example, a literature review of existing studies conducted by CMU [20] indicated that 67-90% reductions in annual churn-related costs could be achieved.

Furthermore, as illustrated in Figure 5, the annual economic benefits per employee were discovered to break down as follows: $30 savings in energy cost, $38 savings in facility management costs, $154 savings in churn costs, and $264 from increased worker productivity (total benefit of $486 per employee and a payback of 0.11 to 0.87 years). Therefore, building owners and operators do not necessarily need to rely on energy savings to demonstrate the economic feasibility of a UFAD system. Even if the benefits are not quite as appreciable as pointed out in the CMU study, owners/operators can select UFAD with the confidence that productivity and churn efficiency will increase noticeably and that significant energy savings will occur.



Source: CMU (2004).

Figure 5. Savings per Employee from Implementation of UFAD Technology

One of the most significant challenges associated with selection and implementation of UFAD is humidity control. In most regions of the U.S., delivering 63-68°F air during the cooling season will result in uncomfortable relative humidity (RH) levels within the occupied space and thus make the choice of UFAD untenable. Listed below are the three most common design strategies utilized to rectify this problem:

- *Primary Air Stream Pre-cooling.* In most conventional OH systems, primary and/or return air crossing the cooling coil is cooled to the apparatus dew point (ADP), commonly 50-52°F, thus producing a supply air temperature of approximately 55°F. Sufficient moisture is condensed out of the air stream onto the coil to result in acceptable RH values within the space. The supply air is then reheated to temperatures desired by most occupants (*e.g.*, 65°F or higher)—a necessary process but one that is very wasteful of energy. In primary air stream pre-cooling, the return air from the occupied space is used to "reheat" the cooled and dehumidified supply air stream. Because the return air stratifies within the space, warmer air from the upper layers can be efficiently captured in the return air stream through a ceiling plenum or grilles located high along the interior walls. The disadvantage of this approach, however, is that the incoming air still needs to be pre-cooled for dehumidification purposes, thus requiring lower water-side temperatures and increasing chiller energy consumption.

- *Slip-Stream Partial Air Cooling and Mixing.* This approach provides the benefits of primary air pre-cooling with potentially less chiller load. The incoming primary air stream is divided—part is passed over a cooling coil and dehumidified (*i.e.*, at ADP conditions), while the remainder is mixed with return air from the occupied space. The temperature and RH of the return air are too high for comfort conditions within the space; however, they are each lower (*i.e.*, cooler and drier) than the incoming primary air. Thus, the return air mixing helps reduce the sensible cooling and dehumidification load on the cooling coil, which in turn reduces required chiller energy output (either through less total chilled water consumption and/or a higher chilled water temperature). Return air/primary air mixing is often accomplished within the floor plenum, thus minimizing ductwork (capital costs) and pressure drop (fan capital cost and energy cost during operation).

- *Local Temperature and RH Balancing*. Local temperature/RH balancing is always an option, especially for perimeter zones and zones where non-standard conditions must be maintained (*e.g.*, data centers, laboratories, etc.). The potential advantage of this method is greater flexibility, *i.e.*, only one or two types of supply air stream conditions need be provided by the central HVAC system, which is then adjusted at the point of delivery as necessary. However, total capital costs and energy costs may be higher than other alternatives—higher capital costs due to more fans and terminal boxes and greater energy costs due to operation of those fans (as well as slightly greater electrical energy for the added controls). Furthermore, the increased complexity of the system and potential trim and balancing challenges (compared to a pressurized UFAD plenum with one central fan) may result in increased downtime and should only be contemplated for facilities with skilled and experienced HVAC operators.

Other barriers, as noted by Bauman and Webster [11], include the following:

- Lack of familiarity with the technology, which can cause overpricing, inadequate construction, extra costs, and occupant dissatisfaction once operation is underway.

- Lack of design guidelines. (This is gradually being rectified.)

- Gaps in understanding fundamental principles that affect technology performance, such as room air stratification, heat transfer/energy balances around raised floor slabs, and few whole-building energy simulation models that can readily model UFAD systems.

- Perceived greater costs, *i.e.*, when building planners and designers neglect or fail to consider lifecycle costs and properly accounting for large potential savings in churn costs and increased worker productivity. (Refer to Figure 5.)

- Difficulties in applying the technology during building retrofits (clearance, stair and elevator landing rework, lavatory floor reworks).

- Inflexibility of required or accepted standards, although this is changing (*i.e.* ASHRAE Standards 55 and 62.1 have recently been modified to be more inclusive of UFAD systems and their particular characteristics).

- Narrow interpretations of existing building or fire codes by local officials, which may discourage or prohibit large, open floor plenums that also contain electrical cabling.

Daylighting

Overview and Energy Savings Potential

Daylighting, as the term is commonly used, consists of an integrated strategy to maximize admission of visible light to a building's interior, while simultaneously avoiding or minimizing deleterious effects such as solar heat gain and glare. This can be accomplished using a wide range of strategies, as follows:

- *Building Orientation*. Notwithstanding potential constraints of the building lot and the climate in which it is located, buildings oriented with their long axis East to West will exhibit better daylighting performance. This orientation admits the greatest amount of visible light during summer months from the high-angle sun, while also allowing the low-angle sun (beneficial solar heat gain) to enter from the North during winter months. In addition, minimizing light transmission through the East and West dimensions of the building is generally beneficial because it limits solar heat gain associated with sunlight from those directions.

- *Window Glazing and Design*. Window design is comprised of two elements: (1) the construction of the window, itself; and (2) the locations, shapes, and orientations of windows and appurtenances. The types of advanced windows that are employed for daylighting generally have some or all of the following features:

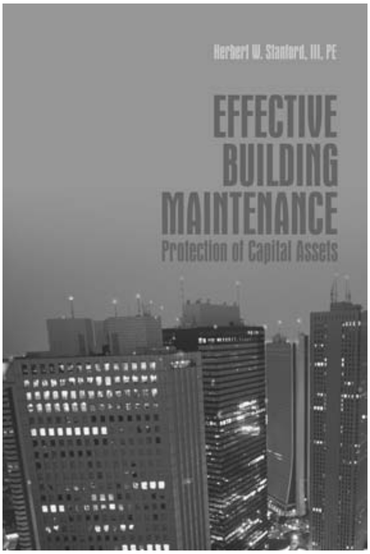
    (1) Double-, triple-, or quadruple-glazing and air or inert gas filler (*e.g.*, argon, krypton) to minimize conductive heat loss during the heating season.

    (2) High visible light transmittance (generally greater than 70%).

    (3) Spectrally selective metal oxide coatings that admit wavelengths within the visible band while blocking infrared wavelengths (*i.e.*, undesirable heat gain in summer and heat loss in winter).

EFFECTIVE BUILDING MAINTENANCE: PROTECTION OF CAPITAL ASSETS

Herbert W. Stanford III



The maintenance of a commercial building or facility can in large measure be considered the protection of an important capital asset. This text examines in depth the requirements for effectively designing, implementing and managing both programs and procedures for all areas of building maintenance, from the foundation to the roof, including interior and exterior support systems, as well as sitework elements. Discussed in detail are programmed maintenance as a critical part of asset management, maintenance planning and budgeting, outsourcing of maintenance services, computerized maintenance management, planned replacement vs. major renovation, preventive and predictive maintenance, and energy efficiency, indoor air quality and sustainability considerations. Also explored is the topic of designing a building for effective maintainability, including general construction, plumbing, HVAC and electrical systems.

ISBN: 0-88173-638-4

6 x 9, Illus., 428 pp., Hardcover

ORDER CODE: 0643

CONTENTS

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Effective Building Maintenance: Protection of Capital Assets	**0643**	**$98**	

Applicable Discount	
Georgia Residents add 6% Sales Tax	
Shipping Fees	**10.00**
TOTAL	

② Indicate shipping address: **CODE: Journal 2010**

NAME (Please print) BUSINESS PHONE

SIGNATURE (Required to process order) EMAIL ADDRESS

COMPANY

STREET ADDRESS ONLY (No P.O. Box)

CITY, STATE, ZIP

MEMBER DISCOUNTS
A 15% discount is allowed to AEE members.
☐ **AEE Member (Member No.____________________)**

③ Select method of payment:
☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

Make check payable in U.S. funds to:
AEE ENERGY BOOKS

CARD NO.

Expiration date *Signature*

④ Send your order to:
AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

INTERNET ORDERING
www.aeecenter.org

TO ORDER BY PHONE
Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.

SUSTAINABLE DEVELOPMENT HANDBOOK, Second Edition

Stephen A. Roosa, Ph.D.

Now available in its fully updated second edition, this important reference provides a thorough examination of recent and ongoing developments, as well as current trends in all areas of the growing field of sustainable development. Sustainable development is a concept that incorporates energy, urban management, environmental objectives, policy integration, and the idea that effective solutions can be achieved in a cooperative manner with concerted effort. Gaining momentum on the world stage in recent years, sustainable development is beginning to significantly redefine the policies and decision making of both corporations and governmental entities. Sustainable development initiatives can vary widely in both scope and application, as well as in success. This book is intended to clarify critical issues, proven approaches and potential pitfalls associated with such initiatives, covering underlying concepts, renewable energy solutions, environmental issues, green design and LEED® programs, sustainable industrial processes, sustainable development policy considerations, local government programs, corporate programs, tracking results, and future trends. This second edition includes complete updates on measurement and verification for LEED projects, as well as a new chapter on cities and carbon reduction.

ISBN: 0-88173-636-8
6 x 9, Illus., 478 pp.,
Hardcover

ORDER CODE: 0642

CONTENTS

1– What Is Sustainable Development?
2– Sustainable Development: A New Social Concept
3– The Environment & Sustainable Development
4– Sustainable Buildings
5– Sustainable Energy Solutions
6– Corporate Sustainability Programs
7– Local Politics for Sustainable Development
8– How Sustainable Development Policies Affect Planning
9– Tracking Local Sustainable Development
10– Learning from Las Vegas
11– Local Carbon Reduction Policies
12– International Sustainability
13– What the Future Holds: Creating a Sustainable World

Bibliography, Appendices, Index

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Sustainable Development Handbook	**0642**	**$135.00**	

② Indicate shipping address: **CODE: Journal 2010**

NAME (Please print) BUSINESS PHONE

SIGNATURE (Required to process order) EMAIL ADDRESS

COMPANY

STREET ADDRESS ONLY (No P.O. Box)

CITY, STATE, ZIP

Applicable Discount	
Georgia Residents add 6% Sales Tax	
Shipping Fees	**10.00**
TOTAL	

MEMBER DISCOUNTS
A 15% discount is allowed to AEE members.
☐ **AEE Member (Member No.____________________)**

③ Select method of payment:
☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

Make check payable in U.S. funds to:
AEE ENERGY BOOKS

CARD NO.

Expiration date *Signature*

④ Send your order to:
AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

INTERNET ORDERING
www.aeecenter.org

TO ORDER BY PHONE
Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.

(4) Window frames and sashes with thermal breaks, which are low-thermal conductivity materials (*e.g.*, polyurethane) situated between the inner and outer window sashes.

The placement and size(s) of windows are also extremely important. Windows need to be located not only where they will receive the largest amounts of visible light, but also where they will minimize solar heat gain during the cooling season. In addition, the window is only the first gateway for admitting visible light to the space; as discussed in the next bullet, incident light rays often must be focused and redirected to maximize penetration depth and prevent undesirable effects such as glare and brightness. Thus, the window and the interior reflecting surfaces form an integrated system, and neither can be designed exclusively without considering the other.

- *Focusing and Redirection of Incident Light*. Direct, intense sunlight is usually not desirable because it is more likely to do the following: (1) transmit infrared energy to the space; and (2) reduce worker productivity due to glare and brightness. Therefore, most current daylighting systems and strategies rely on dispersing incident light rays while reflecting them (at a lesser intensity) to the work surfaces inside the space (*e.g.*, desks, tables). The most traditional type of light-redirecting device is the parabolic reflector provided with many straight-tube fluorescent tube fixtures; these reflectors can form a part of the overall daylighting strategy. Other common types of immobile structures include light shelves, overhangs, and light pipes. Light shelves are flat, highly reflective surfaces that are used to scatter and/or refocus light that enters the space at too great an intensity. Overhangs are horizontal protrusions often installed higher up along a wall and serve two purposes:

(1) Provide shading for low windows.
(2) Block and deflect infrared radiation from high-angle summer sunlight, while still allowing transmission of visible light to the space through clerestory windows.

Light pipes are open ducts which, once they capture sunlight, redirect it deeper into the space to areas that normally would not receive sufficient daylight for task work. Lastly, perhaps the most advanced (but also most complex) type of system in this category consists of movable louvers or reflectors that automatically track the Sun's position as it travels across the sky during the daytime.

- *Feedback Controls for Artificial Lighting*. Feedback-type controls have been used in all types of buildings for many years. These controls include photo-sensors, dimmers, occupancy sensors, and timers. Photo-cell sensors are used to measure ambient light levels inside the space. Based on those readings and the selected foot-candle (fc) thresholds (which may vary depending on uses and activities in each area), the system may take one of two actions:

  (1) Close louvers to partially or totally block out the incident light; and/or

  (2) Activate dimmer switches that reduce (or completely shut off) electric lighting.

  In addition, the familiar ultrasonic or passive infrared occupancy sensors may be installed in transient or low-occupancy areas (*e.g.*, restrooms, break rooms, closets) or in private offices. Photo-cells and occupancy sensors either use variable or stepped dimming, or completely shut off lighting when the space is unoccupied. Lastly, the potential benefits of simple timers should not be ignored for areas that have set, uniform occupancy schedules; they provide a simple and cost-effective tool for reducing wasteful energy consumption.

Results of Literature Survey and Modeling

Energy savings estimates for daylighting collected from several sources of information (including operating facilities and modeling studies) are graphed in Figure 6 and further described in Appendix B, Table B-2. As indicated in Figure 6, the computed total energy savings associated with daylighting for the test building, compared with the base case, was approximately 18%, thus generally conforming to the data from other operating buildings and modeling studies. The energy consumption reduction compared with the 2003 CBECS average for office buildings (approximately 38%) is also presented in Figure 6.

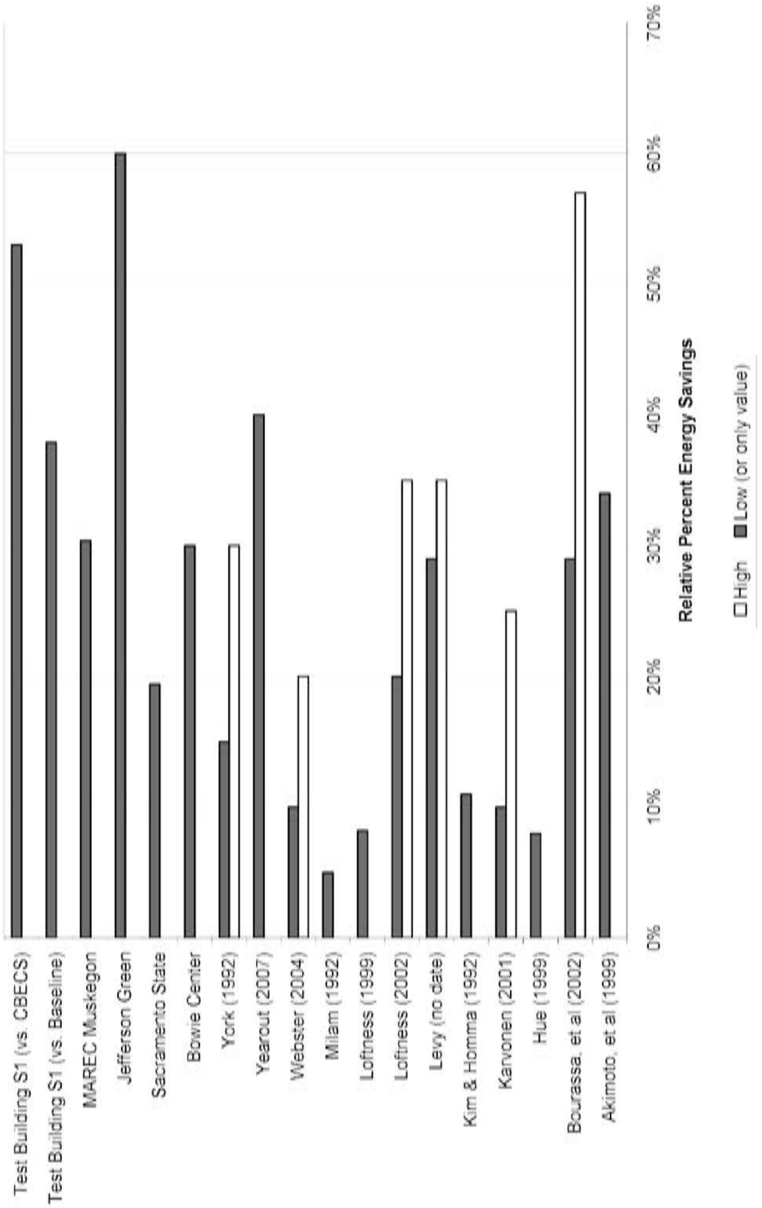


Figure 6. Energy Savings from Daylighting

Additional Benefits and Limitations

Additional benefits (other than energy savings) of daylighting have been well summarized in the literature and include some or all of the following:

- A wide spectrum of strategies and technologies, with various cost options. (Thus, nearly any project can afford to incorporate at least some daylighting features.)
- Significant improvements in worker productivity. (Refer to the discussion below.)
- Utilization of a free resource—the sun.
- Simple design elements with minimal or no incremental costs, such as light paint and cubicle partition colors, can greatly complement the daylighting design for a facility and contribute to significant energy savings.
- The behavior of light follows the principle of complete similitude; thus, daylighting designs can be very accurately tested using small-scale models. (Often, light photometers and/or cameras are placed inside the model to obtain measurements and images that facilitate analysis and fine-tuning of the design.)
- As indicated in Appendix A, Table A-2, implementation of daylighting strategies can earn a project LEED-NC® points for direct daylighting as well as for views to the exterior.
- Daylighting glazing can be combined readily with newer BIPV products, or windows can be alternated between daylight glazing and BIPV coatings (e.g., the “saw-tooth” roof configuration).

Limitations of daylighting include the following:

- Less effective in regions with a high incidence of cloudy days, such as the Pacific Northwest and states leeward of the Great Lakes.
- If not properly designed, an attempted daylighting system can cause worker discomfort, productivity impacts, and/or undesirable heat gain and significantly higher cooling energy costs.

- Most designs must use dimmable electronic ballasts; therefore, for retrofits/renovations, ballast replacement costs could be significant.

- There is no effective "cookie cutter" approach for daylighting—each site demands a unique daylighting design, which increases architectural and engineering design costs.

- There is a tradeoff between increased window glazing area, savings from daylighting, and fenestration heat loss and gain. Generally, the optimum glazing area to best promote daylighting while minimizing losses is a site-specific value(s) that must be derived through complex analysis and modeling.

As with UFAD systems, worker productivity increases can range from significant to remarkable and are often the key rationale for investing in daylighting design and equipment. For example, a study conducted by Carnegie Mellon University (CMU) and DOE indicated health complaints (*e.g.*, clinical sunlight deficiency syndrome, depression) were at a 23% lower rate in day-lit buildings [57]. In a more dramatic and well-known case study, an extensive daylighting system installed in Lockheed's Building 157 (Sunnyvale, California) resulted in a 15% reduction in absenteeism rates and simultaneous 15% increase in productivity [77]. Reportedly, the absenteeism savings alone in the first year of operation paid back the incremental capital costs associated with the daylighting measures.

It is also vital not to overlook testing of all key elements of the daylighting system during facility commissioning. Even though design deficiencies may not be completely or quickly repairable, commissioning can identify the problems and allow for workarounds or temporary adjustments to be made, to limit worker discomfort without new capital investment.

Energy Savings from Combined UFAD and Daylighting

Through review of the available literature, six buildings that utilize both UFAD and daylighting were identified. Figure 7 indicates the reported energy savings for each. Additional data for these projects is included in Appendix B, Table B-3. In addition, scenario S3 for the test building was modeled using the eQUEST™ software.

Scenario S3 included simultaneous implementation of UFAD and daylighting, while retaining the specific assumptions for each technology used in the two previous scenarios (S1 and S2). As illustrated in Figure 7, the relative energy savings in S3 (50% compared with the base case and 62% compared with the 2003 CBECS average for office buildings) conform to the data from other operating buildings and modeling studies.

Additional Targeted Electricity Savings

As is evident from Table 3 and Figure 8, after the utilization of UFAD and daylighting, the energy usage profile for the test building remains significant in four areas: (1) space cooling (*i.e.*, chiller load); (2) ventilation fans; (3) miscellaneous equipment (*i.e.*, plug loads); and (4) area lighting. To further explore potential means for attaining or approaching a net zero energy paradigm for the test building, an additional scenario (S4) was modeled that incorporated four additional energy efficiency measures: (1) high-efficiency chillers, (2) variable speed fans and pumps, (3) reduction in equipment power density (EPD), and (4) reduction in lighting power density (LPD). The detailed assumptions for these additional technologies are displayed in Appendix C. As a result of adding these measures, energy consumption decreased by 15% compared with Scenario S3, and 65% compared with the baseline case. The overall energy savings compared with the CBECs averages for (1) buildings of between 200,000 and 500,000 GSF and (2) all office buildings, were approximately 75% and 73%, respectively. The results for Scenario S4 (as well as for Scenarios S1, S2, and S3) are displayed in Figure 9.

Renewable Energy Strategies

No matter how significant the gains from energy efficiency projects, no building will approach or achieve net zero energy status without on-site renewable energy generation. This is aptly illustrated in Figure 10, which is a histogram of the spectrum of savings realized from energy efficiency projects at the majority of buildings in the DOE's online high-performance buildings database (www.eere.buildinggreen.com). Specifically, the figure depicts the frequency of buildings that have achieved a certain energy consumption reduction below the applicable code benchmark (usually ASHRAE 90.1 but in some cases state codes, *e.g.*, Oregon Energy Code, California Title 24).

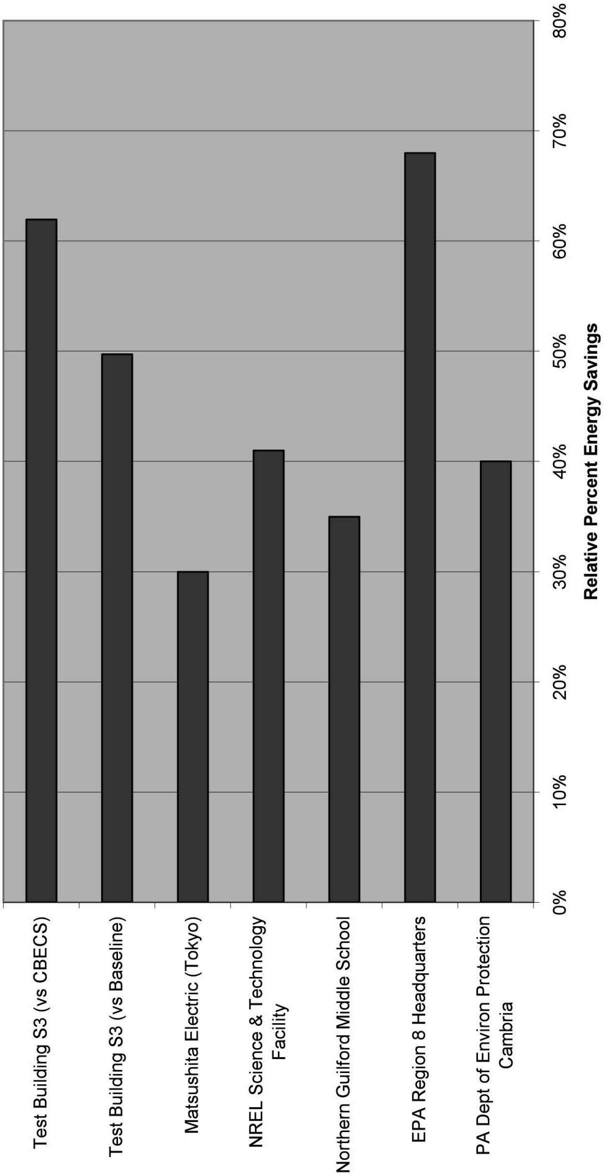


Figure 7. Energy Savings from Combined UFAD and Daylighting

Table 3.

Energy Use[a]	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Electricity Consumption (thousand kWh)													
Space Cooling	7.4[b]	7.1	13.0	24.9	35.3	70.0	85.6	74.4	60.3	25.1	10.6	8.0	421.8
Dehumidification Load[c]	3.2	3.0	5.6	10.7	15.1	30.0	36.7	31.9	25.8	10.8	4.5	3.4	180.8
Heat Rejection[d]	0	0	0	0.2	0.8	3.1	4.4	3.4	2.5	0.3	0	0	14.7
Ventilation Fans	31.3	29.3	34.2	36.5	36.2	46.3	50.1	47.3	42.0	35.4	29.6	33.9	451.9
Pumps and Auxiliary Equipment	12.3	11.7	13.9	14.6	14.0	16.9	17.4	16.5	15.8	14.0	12.0	13.5	172.4
Miscellaneous Equipment[e]	105.6	98.0	111.3	109.7	105.6	109.7	111.3	108.4	106.9	108.4	101.1	111.3	1,287.2
Task Lights	7.8	7.4	8.6	8.6	7.8	8.6	8.6	8.2	8.2	8.2	7.4	8.6	98.1
Area Lights	67.6	63.4	70.7	70.7	64.5	70.1	69.9	67.2	67.8	68.5	63.8	75.4	819.9
Subtotal, Electricity	**235.2**	**219.9**	**257.3**	**275.9**	**279.3**	**354.7**	**384.0**	**357.3**	**329.3**	**270.7**	**229.0**	**254.1**	**3,446.8**
Natural Gas Consumption (million BTUs)													
Space Heating	0.50	0.37	0.23	0.10	0.02	0	0.01	0	0	0.08	0.19	0.38	1.87
Hot Water	0.06	0.06	0.07	0.07	0.06	0.06	0.06	0.05	0.05	0.05	0.05	0.06	0.72
Subtotal, Natural Gas	**0.56**	**0.43**	**0.30**	**0.17**	**0.08**	**0.06**	**0.07**	**0.05**	**0.05**	**0.13**	**0.25**	**0.45**	**2.58**
Equivalent Energy (thousand kWh)[f]	0.17	0.13	0.09	0.05	0.02	0.02	0.02	0.02	0.02	0.04	0.07	0.13	0.76
Total Building Energy Usage (thousand kWh)	**235.3**	**220.1**	**257.4**	**275.9**	**279.4**	**354.7**	**384.0**	**357.3**	**329.4**	**270.7**	**229.1**	**254.3**	**3,447.5**
Energy Intensity (kBTU/SF)	***2.09***	***1.88***	***2.20***	***2.35***	***2.38***	***3.03***	***3.28***	***3.05***	***2.81***	***2.31***	***1.95***	***2.17***	***29.41***

a. All values were calculated using eQUEST™, version 3.6. e-QUEST uses the DOE-2 engine to simulate hourly energy consumption (and savings) performance.

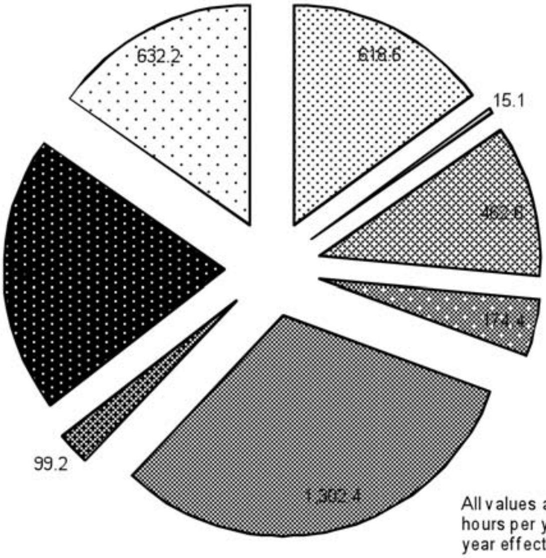
b. The assumptions used to calculate these estimated values are listed in Appendix C of this paper.

c. This line represents the dehumidification requirements, which are not directly calculated by eQUEST™. A sensible heat ratio of 0.7 was assumed in order to derive these values.

d. Energy consumption for operation of cooling tower fan(s).

e. Non-lighting plug loads.

f. Conversion factor: 3,412 BTU = 1 kWh.



All values are in thousand kilowatt hours per year (thousand kWh per year effective for gas consumption).

Figure 8. Relative Energy Consumption by Use Category

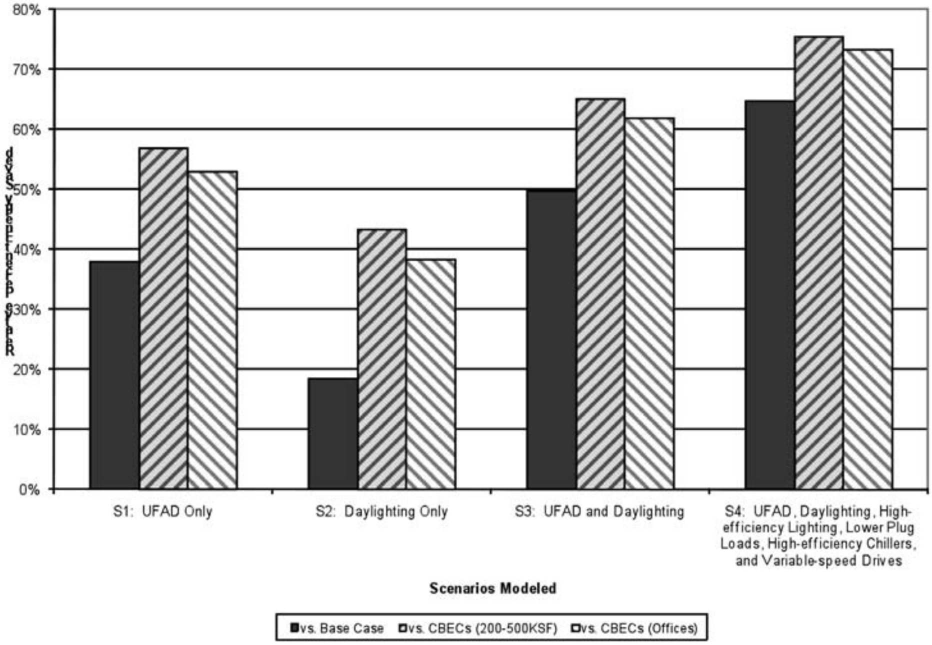


Figure 9. Predicted Energy Savings, Test Building

The cumulative percent reduction curve indicates that for 80%of all facilities in the data set, the energy consumption reduction was 55% or lower. In addition, only two of these facilities have achieved energy savings greater than 70% through energy efficiency measures alone. This renewable energy production must be of a magnitude greater than purely "cosmetic," as discussed in the following paragraph.

When one considers potential on-site renewable energy generation strategies for the test building, it is quickly apparent that they are limited. Technically feasible, proven alternatives such as GSHPs, small wind turbines, wide-area PV arrays, and biomass combustion are limited by probable absence of available space (*e.g.*, for a GSHP well field or large, ground-mounted PV array); aesthetic, noise, and/or vibration concerns (wind turbines); and Clean Air Act and local air regulations, such as State Implementation Plan (SIP) limits (biomass combustion). BIPVs are one of the few (if not only) conditions described for the test building. Therefore, to evaluate the contribution of on-site renewable energy sources, BIPVs were assumed to be the primary (if not sole) technology available.

In downtown Washington, DC, a 10-story high-rise building is going to be among the tallest permitted (*i.e.*, below the spire of the Washington Monument). Therefore, a rooftop array will receive most or all incident sunlight during the year. The NREL's PVWatts, Version 2.1 online tool was utilized to provide month-by-month power output for a rooftop array, which was sized based on the assumptions of: (1) one kilowatt (kW) of peak load capacity per 100 square feet of available space; and (2) 75% of the roof area covered with BIPV panels. Not knowing the use of adjacent properties, the contribution of BIPV elements on windows was assumed to be negligible (although, in reality, the upper-floor windows could be expected to receive significant sunlight).

As illustrated in Figure 11, the addition of a rooftop PV array operating year-round (Scenario S5) would increase the net energy savings by approximately 69% relative to the base case, 79% relative to the 2003 CBECs average for buildings between 200,000 and 500,000 GSF, and 77% relative to the 2003 CBECs average for all commercial buildings. The PV array would not, by itself, be capable of completely netting out remaining energy usage of the building or providing excess power back to the grid.

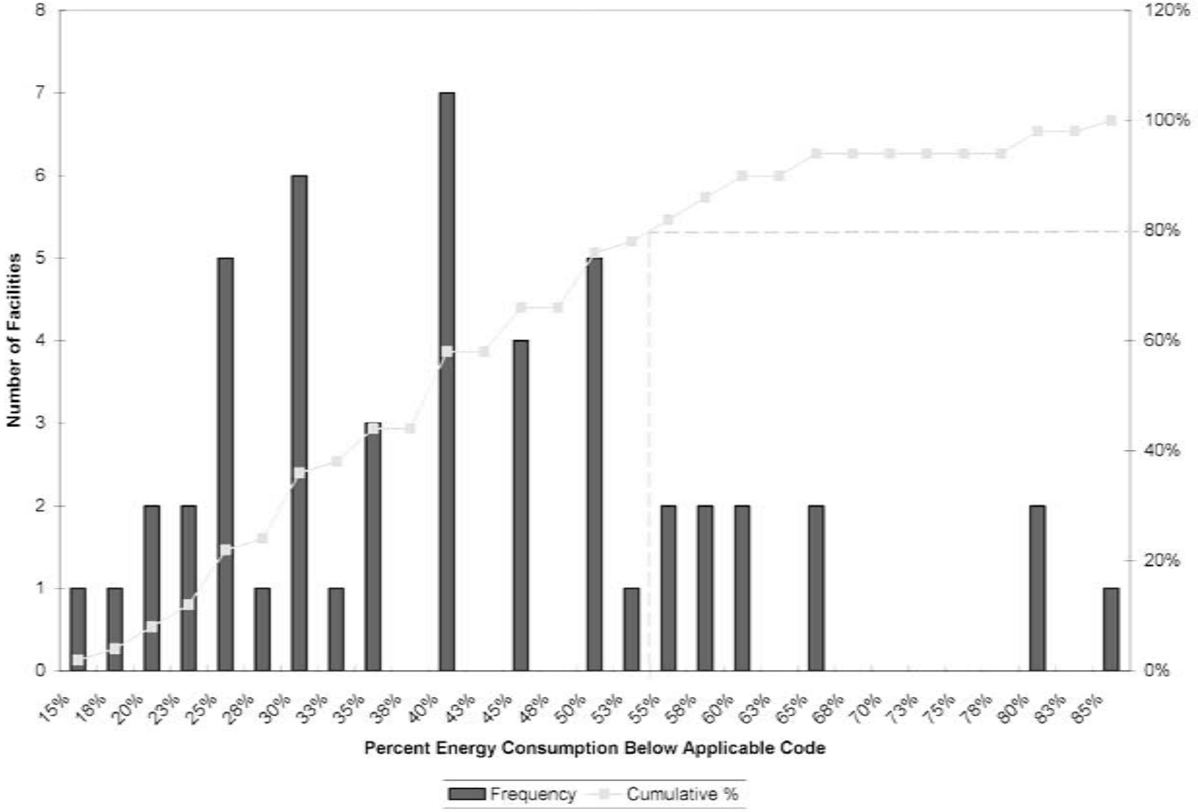


Figure 10. Frequently Distribution of Facility Energy Efficiencies

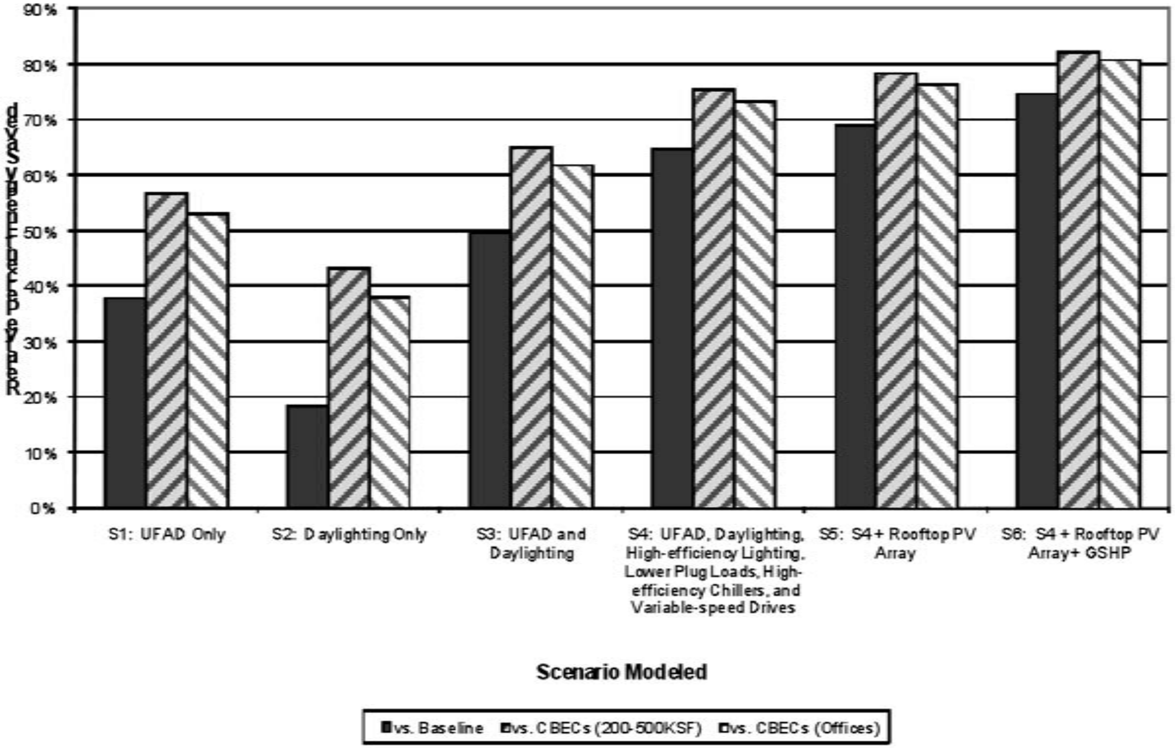


Figure 11. Energy Performance of Test Building, with Renewable Energy Generation

The case involving a potential GSHP is also interesting to analyze; therefore, an additional Scenario (S6) was modeled. S6 assumes that the project site is still urban but not as constrained, and that installation of a GSHP well field is possible. According to the Canada Center for Mineral and Energy Technology (CANMET) [19], the average potential energy savings from a GSHP are approximately 50% in the heating mode and 35% in the cooling mode. As depicted on Figure 11, applying these estimates in conjunction with the other Scenario S5 parameters (*i.e.*, still including the rooftop PV array) results in an estimated energy consumption reduction of 75% relative to the base case, 82% relative to the 2003 CBECs average for buildings between 200,000 and 500,000 GSF, and 81% relative to the 2003 CBECs average for all commercial buildings.

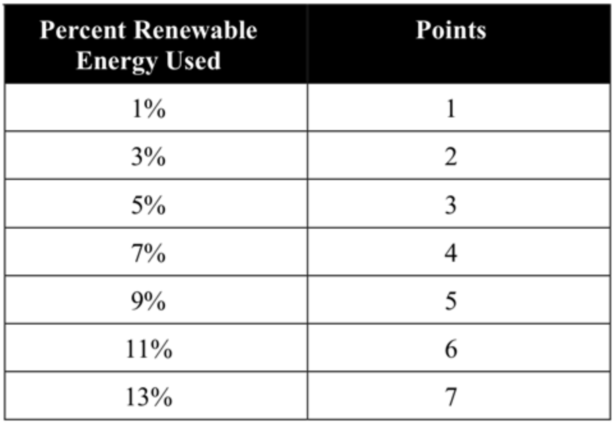
It is also important to recognize that LEED-NC® points are obtainable for implementation of on-site renewable energy technologies. Up to seven total points are available under EA Credit 2, "On-site Renewable Energy," based on the energy produced by the renewable systems as a percentage of the building's annual energy cost, as detailed in Table 4.

Note that solar PV systems are considered eligible renewable energy technologies for LEED-NC® points, but GSHPs are not.

Life Cycle Costs

A complete series of life cycle cost projections was outside the scope of this article. However, for each scenario, the capital cost, energy

Table 4. Leed-Nc® Points For Renewable Energy Use



Percent Renewable Energy Used	Points
1%	1
3%	2
5%	3
7%	4
9%	5
11%	6
13%	7

cost savings, and simple payback period were calculated to create an order-of-magnitude understanding of the relative costs of each option. These are contained in Table 5.

Several interesting findings were obtained upon derivation of these cost estimates. The results can be readily sorted into three ranges: (1) two scenarios, S2 and S4, are easy to justify based on simple payback; (2) one scenario, S3, is borderline but probably justifiable; and (3) the remaining three scenarios, S1, S5, and S6, might require additional rationale outside of cost alone to be practicable.

For this particular project, the renewable energy features (*i.e.*, PV system and GSHP) produce a net energy savings of 756,900 kWh/yr, but at a cost premium of $8.84 million for the energy-saving measures alone (*i.e.*, scenario S6 compared with scenario S4). The unit cost of these two measures alone is $11.68 per kWh of energy savings per year, compared to a total unit cost of $0.435 per kWh of energy saved for the energy efficiency improvements alone (scenario S4). While this should not be a rationale for excluding renewable energy technologies from such projects, it reemphasizes the extraordinary benefits that intelligently applied energy efficiency measures can deliver.

Technical and Cost Barriers

Discussion of the numerous technical and cost barriers associated with achieving a zero energy paradigm could be the focus of a separate, larger study. However, the evaluation conducted for the test building provides valuable insight into a few of these problems, particularly pertaining to high-rise buildings in urban environments. Even after applying numerous energy efficiency measures and a rooftop PV system (*i.e.*, scenario S5), the modeled building still falls short of the EISA 2025 target by 8-9%. The progress toward net zero energy is lower (although still considerable) when the project is evaluated against a base case building that is more typical of today's building stock than the average 2003 CBECs building. Much of this is due to two factors:

(1) *Substantial area lighting and plug load energy consumption.* Area lighting and plug load energy consumption amounts to greater than 1.3 million kWh per year (approximately 63% of the building's total electricity consumption and 44% of the total energy consumption), even after applying reasonable and achievable power density savings measures on both load categories. The energy draws from

Table 5. Costs Associated with Test Building Scenarios

Scenario	Capital Cost Premium[1]	Annual Energy Cost Savings	Simple Payback Period (yr)
S1: UFAD Only	$1,400,000	$219,582	6.38
S2: Daylighting Only	$439,193	$167,494	2.62
S3: UFAD and Daylighting	$1,839,193	$379,264	4.85
S4: UFAD, Daylighting, High-efficiency Lighting, Lower Plug Loads, High-efficiency Chillers, and Variable-speed Drives	$2,321,056	$639,372	3.63
S5: All of S4 Features and Rooftop Photovoltaic System	$4,721,056	$698,707	6.76
S6: All of S5 Features and GSHP	$11,162,723	$777,754	10.66

1. In other words, the incremental costs associated with the unique features of each scenario, only.

lighting and plug loads are a challenge currently faced by most types of buildings, including large office complexes, for which there are currently few if any expeditious solutions.

(2) The inability of this project to produce a sizeable portion of its energy requirements through on-site renewable energy technologies. (Less than 12% of total energy consumption is provided by the rooftop BIPV array.) This deficiency can be attributed in turn to three factors: (a) the limited number of suitable technologies (i.e., technologies other than BIPVs); (b) the limited amount of rooftop space in proportion to total building GSF; and (c) the current conversion efficiencies of available and cost-effective PV cells.

The two more prominent cost barriers for any project will be first (capital) cost and return on investment (ROI). For the test building, the effect of these can be aptly illustrated by considering, for example, scenario S1 (UFAD only). According to Webster [102], the average incremental cost of a UFAD system is approximately $3.50 per GSF; for the test building, that would produce an incremental total cost of $1.4 million. In the context of the total project costs, this is not very high, since a typical DC office tower could cost $250 per GSF or greater (*i.e.*, total cost of $100 million or greater). Using the calculated energy savings and current local electricity and gas rates in the Washington, DC area, annual cost savings would be approximately $219,600, which translates to a payback period of 6.4 years. This might be considered a marginal payback (*i.e.*, not all investors would find it acceptable). In addition, even where a 6.4-year payback would be acceptable, an increase in the capital cost of the UFAD system might reverse an initial decision to install the system. For example, an increase in capital cost to $4.00 per GSF would increase the payback to 7.5 years, and an increase to $5.00 per GSF would increase the payback to 9.4 years.

Emerging Technologies

It is clear from the analysis presented above that while conventional technologies can produce very substantial progress toward the net zero energy building paradigm, additional technologies (or improvements to existing technologies) may be required. The candidate technologies and improvements are too numerous to fully discuss in this article. Three emerging technologies that are intriguing in their fundamental operating concepts are (1) chilled beams, (2) magnetic levitation (maglev) chillers, and (3) small-scale hybrid solar/wind energy generators. A brief description of each technology is provided in the following paragraphs, and the advantages, limitations, and example installations are presented in Table 6.

Chilled Beams

Chilled beams have been widely used in Europe, and are gradually being introduced into the U.S. market. Typically, a distinction is made between "passive" and "active" systems:

- Passive chilled beams consist of small heating and/or cooling coil(s) located inside a recessed or ceiling-hung, perforated sheet metal box. The chilled or hot water flow establishes natural convection currents within the room that transfer energy toward or away from the beam, as required. However, given that natural convection is the only driver, the occupants have no ability to modulate the airflow.
- Active chilled beams drive a fixed or variable air stream through the beam (typically a horizontal square duct) and over the coil(s). Diffusers on either side of the beam release small air jets to the space immediately below the beam, which induce airflow/circulation from the lower areas of the space. The combined primary ventilation air stream and induced airflow (*i.e.*, the total ventilation delivered to the occupied zone) is approximately three times larger than the induced air flow entering the beam.

The heat transfer capacity of active chilled beams typically varies from 80 to 800 Btus per hour per linear foot. Integrated fluorescent lamp fixtures are available. This technology is obviously easier to install in suspended ceilings, but hard ceiling installations are possible as well.

Chilled beams can be utilized in a wide variety of settings, including offices, schools, hotels, and health care facilities. However, they are gaining particular interest from laboratory developers and operators. Due to safety and industrial hygiene requirements, laboratory exhaust systems must move large quantities of air, and any incremental air required for space conditioning thus becomes costly. Most laboratories have overall cooling loads of between 10 and 20 Watts per GSF, and ventilation requirements of between six and 12 air changes per hour (ACHs).

Table 6. Summary of Several Emerging Technologies for Potential Application in Net Zero Energy Buildings

Technology	Advantages	Limitations	Example Applications
Chilled Beams	• 15–20% savings in chiller energy, due to chilled water temperatures in the 55–60°F range (as opposed to 45–50°F). • 40%–70% less airflow than conventional system; hence, a significant reduction in capital cost of airside systems (ductwork, air handlers, fans). • Less noise (*i.e.*, 10 dBA lower than comparable VAV system). • Typical cold deck of 58–60 F and hot deck of 90–100 F are very compatible with energy output from a GSHP. • Favorable for refurbishment projects where limited ceiling space for ductwork is available. • Reduced O&M costs (less particulate deposition in ductwork to clean out, no filters at terminal box requiring change-out, no moving parts in the beam assembly requiring lubrication or servicing[1]).	• Even with the reduced HVAC infrastructure (see Advantages), capital cost is still often 5–10% higher than that of a similarly-sized VAV system. • Typical chilled water temperatures are very close to the dew point, and must be carefully controlled to avoid excess condensate formation. • Difficult to implement in spaces with the following features: (1) high ceilings (10–12 ft or higher), (2) high sensible cooling loads (greater than 60 BTUh/GSF), (3) high relative humidities (*e.g.*, gymnasiums, swimming pools), (4) potential large volumes of air infiltration (*e.g.*, lobbies), and (5) unstable or rapid ramp-up loads. For areas with high humidities, separate dehumidification strategies (*e.g.*, desiccant wheels or slip-stream mixing with supercooled air) may be necessary. • For active chilled beams operating at high airflow rates, noise associated with the induction nozzles can become an irritant.	• ***Tahoe Center for Environmental Sciences (Incline Village, Nevada).*** Approximately 10,000 GSF of laboratory space is equipped with active chilled beams.[2] The airside system capacity (AHUs, ductwork) was reduced by one-third, compared with a standard system. Total annual HVAC energy cost savings have been approximately 57%. Capital cost savings was not as high as hoped ($19,000 or 2.6%), due to greater-than-anticipated design costs and contractor bids (it was the first chilled beam system installed in a laboratory in the state of Nevada). *Note: Because of large diurnal temperature cycling and moderate summertime temperatures in this climate, all chilled water at this facility normally can be generated using a cooling tower and overnight thermal storage tank (*i.e.*, no chillers are required). In most areas of the U.S., this would be impracticable.*
Magnetic Levitation (Maglev) Chillers	• Manufacturer claims 30% energy savings over typical screw compressor and 40–50% savings over typical reciprocating compressor. • Due to lack of wear, costly compressor rebuilds (*e.g.*, $30,000 every five years) are avoided. • Oil-less equipment; therefore, is little or none of the following: (1) labor and materials costs associated	• Although friction losses are eliminated, other losses are present; *i.e.*, heat loss in the copper windings, hysteresis (flux density deterioration), eddy currents, and air drag in the rotors. • 20% premium on capital costs, compared with conventional chillers. • Maglev compressors must be provided with an integral backup power supply, or the impeller shaft and bearings may be	• ***U.S. Embassy, Tokyo, Japan***. Twelve (12) modular maglev chillers providing a combined 720 ton R. Projected energy savings of 30%; capital cost = $2.8 million; expected payback = 10 years. • ***U.S. Embassy, Geneva, Switzerland***. One maglev chiller rated at 225 ton R. Projected energy savings = 30%.

Technology	Advantages	Limitations	Example Applications
	with oil changes, (2) used oil disposal costs, or (3) spill risks. • No vibration (no reciprocating mass elements or metal-on-metal contact). • Very low noise, compared to conventional chillers.	significantly damaged during a primary power supply interruption. • Limited commercial track record; energy savings and 25-year lifecycle claimed by manufacturer are estimates pending validation.	
Hybrid Solar and Wind Generating Units	• Can provide more continuous power output than solar arrays or wind turbines alone (*e.g.*, at night if wind speed is high or in daylight if wind speed is too low). • Manufacturer claims that placement of PV cells on the wind vanes increases power output by 30–35% compared with a standard wind turbine. • The units are manufactured using a fast-molding process (90-second cycle time) in aluminum molds, without use of release agents, thus minimizing environmental impacts from the manufacturing process.	• Payback period of between 10 and 18 years (high-end estimate is for a location with no available subsidies from utility or state or local governments). • If installed on top of a building, it is unclear how the unit will perform under turbulent flow conditions prevalent there (most wind turbines perform best under laminar flow). • Limited commercial track record, little or no information available regarding in-field performance.	• Unknown

1. Supply and/or return fans associated with the building ventilation system would require periodic maintenance.
2. Two small laboratory areas that require more intensive cooling were equipped with conventional fan-coil systems rather than chilled beams.
2. Electricity cost = $0.11 per kWh, and natural gas cost = $1.03 per therm.

°F – degrees Fahrenheit; VAV – variable air volume; ton R – tons of refrigeration; PV – photovoltaic; BTUh – British Thermal Units per hour; GSF – gross square feet; O&M – operation and maintenance; HVAC – heating, ventilation, and air conditioning; AHU – air handling unit

If a standard VAV system is used, an additional 2 to 11 additional ACHs *above the minimum ventilation requirement* will be needed to cool the laboratory space to comfortable conditions. This can impose very substantial increases in fan energy, as well as in chiller load. Because chilled beam systems use water as the primary heat removal medium, and water has a volumetric heat capacity 3,500 times greater than air, chilled beams begin to become economical as required ACHs increase much above the minimum ventilation requirement.

Maglev Chillers

Maglev chillers utilize a vapor compressor, consisting of an impeller and vanes similar to a conventional compressor. The difference is that the impeller shaft is balanced, using powerful magnets instead of physical bearings, which aids in conquering the mechanical engineer's perpetual arch-enemy—friction. While the concept of magnetic, frictionless bearings originated in the 1940s, their commercial feasibility was only made possible by recent developments in digital controls. These controls are able to make the nanosecond speed adjustments necessary to keep the impeller shaft balanced within the requisite microscopic tolerances. Several recent installations by the U.S. State Department in overseas embassies have garnered significant publicity. (Refer to Table 6 for details.)

Hybrid Solar/Wind Energy Generators

A company called Blue Energy USA, located in New Mexico, is advertising a product called the Solarwind Turbine, which integrates solar- and wind-generating equipment together in a single device. The apparatus consists of a double helix-shaped wind vane, with solar PV cells encapsulated on the surfaces of the vane. Microscopic indentations on the PV cells capture, direct, and redirect incident sunlight to concentrate it, without requiring tracking mechanisms or special optics. The spinning vanes drive a generator, and the PV panels' output is combined through a single inverter. Reportedly, models in sizes rated up to 8 kW are offered, and a 5 kW unit fits within a 60-square foot footprint (approximately 8 ft by 8 ft). Double-frictionless bearings aid in self-stabilizing the unit in high winds, thus reducing stresses on the housing and undesirable vibrations.

According to the manufacturer, an 18-year performance test on this technology has been conducted in Germany. Neither results from this testing nor information regarding any U.S.-based installations were available.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results presented above, the following conclusions were obtained:

- LEED® was found to provide a valuable, fundamental design philosophy (*i.e.* a "road map") for addressing the challenge of attaining significant energy consumption reductions (and resulting fossil fuel use reductions) at federal facilities. Selecting technologies such as UFAD and daylighting at the design stage can result in considerable LEED-NC® points *and* in notable energy savings during facility operation. While not the focus of this article, in most situations, these technologies would also be expected to aid in obtaining considerable LEED-EBOM® points during facility operation.

- High levels of building energy consumption reduction can potentially be achieved even at projects facing significant site-related and operational constraints (*e.g.*, the test building modeled herein). Based on the limited analysis conducted in this article, it is reasonable to surmise that energy reductions exceeding 80% below the 2003 CBECS average could be achieved in practice, which is greater than the 2020 EISA target.* Even though using the 2003 CBECS baseline inflates the apparent energy savings, the test building sustainability scenarios nonetheless performed well relative to a typical, current, well-designed office tower (*i.e.*, the baseline case).

- This article highlights a central tenet: Except in highly favorable situations, with today's technology it is difficult or impossible for buildings to achieve NZEB status. The role of emerging technologies, both on the demand (*i.e.*, energy efficiency) and supply (*i.e.*, renewable energy production) sides will be pivotal. This article

---

*Assuming a direct correlation between total and fossil fuel energy consumption.

briefly introduced three candidate technologies, but there are many others. Implementation of emerging and innovative technologies is nearly always accompanied by performance and cost risks; these must be diligently evaluated prior to proceeding, and actively managed or minimized once the facility is operational.

- The capital costs associated with implementation of aggressive energy reduction programs are often large. For example, to incorporate all of the net energy reduction strategies assumed for scenario S6 of the test building (UFAD, daylighting, high-efficiency chillers, high-efficiency lighting/low lighting power density, lower equipment power densities, rooftop PVs, and GSHP[s]) would increase project capital costs by almost $12 million. For many projects, the aggregated financial benefits from energy cost savings, worker productivity increases, and cost savings during churns will offset the incremental capital costs within a few years. However, obtaining the initial capital or budget resources is a constant challenge for organizations, federal and non-federal alike. Therefore, mechanisms such as tax rebates and energy savings performance contracts (ESPCs) should be thoroughly considered, notwithstanding the increased planning and administration burdens/costs associated with these options.

While each project will have its site-specific requirements and challenges, several general recommendations for federal energy and environmental managers can be offered:

- Compile a list of upcoming and future anticipated projects and begin to assess the specific technologies or methodologies that would potentially be suitable, based on site layout, local climate, type of operation(s), and other facility-specific factors.

- Continually monitor the evolution of emerging energy efficient and renewable energy production technologies (in particular energy and carbon savings)
in-field performance track records, costs (capital and operating), and other benefits and risks.

- Use LEED-NC® as a fundamental system and tool to aid in preliminary selection and further detailed evaluation of candidate technologies and strategies. Understand the strengths and limitations and recognize that there are many possible pathways to Certified, Silver, Gold, or Platinum status, not all of which guarantee that the project will be an NZEB. LEED-NC® must therefore be strategically applied to yield best results, and it is often advisable to begin with consideration of the benefits, costs, and risks that particular technologies will deliver in addition to maximizing LEED-NC® points.

- Establish a robust monitoring and tracking system to evaluate building energy performance. With the types of building automation systems commercially available today, most or all of the key parameters can be continuously sampled, stored in digital form, and then transferred to a remote computer for trend analysis.

Through EISA, Congress has transmitted a mandate to the federal government, namely to be at the forefront of the NZEB groundswell. Especially interesting is the response in terms of research and development (R&D) and deployment initiatives, both those that are directly government-driven and those in the private sector. Most are familiar with the American Recovery and Reinvestment Act of 2009 (ARRA) spending being allocated by DOE. As one of many examples, on June 2, 2009, Dr. Stephen Chu, the Secretary of Energy, announced that the DOE is committing $50 million in direct investment for increasing deployment of GSHPs, including innovative technology demonstrations, new lifecycle costing tools, and a national certification and accreditation program for the GSHP industry. A private sector parallel is Daiken McQuay's opening of a 49,000 GSF R&D facility in Plymouth, Minnesota, to research and test advanced chillers and other HVAC technologies. (Incidentally, this facility was designed to itself achieve LEED-NC® Silver certification.) In summary, these projects are evidence of a widespread recognition that advancing up the technology curve represents the most credible strategy to deploy NZEBs. Notwithstanding this, as demonstrated in Figure 1 of this article, current energy efficiency and renewable energy production technologies will continue to occupy an indispensable role in the net zero energy equation.

References

Aitken, D.W., 2000. Why Are Buildings So Important, and How Does "Cool Daylighting" Provide Benefits? A Global Climate and Local Economic Perspective. Daylighting Collaborative/Energy Center of Wisconsin. December 7.

Akashi, Y. and P. Morante, 2004. Daylight Dividends Case Study: TomoTherapy, Inc., Madison, Wisconsin. Lighting Research Center. Rensselaer Polytechnic Institute.

Alexander, D. and M. O'Rourke, 2008. Design Considerations for Active Chilled Beams. *ASHRAE Journal*. pp.50-58. September.

American Power Conversion, 2003. How and Why Mission-Critical Cooling Systems Differ from Common Air Conditioners. White Paper #56, Revision 2.

American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE), 2006. ASHRAE GreenGuide—The Design, Construction, and Operation of Sustainable Buildings. Elsevier. ISBN 1-933742-07-0.

American Standard, Inc., 2007. Trane Quick Reference Guide for Efficient Chiller System Design. CTV-TRT001-EN. August.

Ander, G.D., 2008. Windows and Glazing. Southern California Edison. www.wbdg.org/resources/windows.php. May 26.

Ander, G.D., 2008. Daylighting. Southern California Edison. www.wbdg.org/resources/daylighting.php. May 12.

Architectural Energy Corporation, no date (downloaded March 2009). Design Brief: Underfloor Air Distribution and Access Floors. www.energydesignresources.com.

Balboni, B. (editor), 2006. RS Means Square Foot Costs, 28th Annual Edition. Reed Construction Data, Inc.

Bauman, F. and T. Webster, 2001. Outlook for Underfloor Air Distribution. ASHRAE Journal. pp.18-24. June.

Bhatia, A., date unknown (downloaded March 2009). HVAC—Overview of Underfloor Air-conditioning Systems. PDH Course M217. www.pdhcenter.com.

Bluenergy Solarwind, Inc., 2006. Producing Renewable Energy with a Hybrid Bluenergy Solarwind™ Turbine. www.bluenergyusa.com. October 15.

Bourassa, N., P. Haves, and J. Huang, 2002. High Performance Commercial Building Systems: A Computer Simulation Appraisal of Non-residential Low Energy Cooling Systems in California. Lawrence Berkeley National Laboratory (LNBL) Report No. 50677. May.

Boyce, P., et al, 1997. Lighting Case Study: Sacramento Municipal Utility District Customer Service Center, Sacramento, California. Lighting Research Center, Rensselaer Polytechnic Institute. November.

Brons, J., 1998. Daylight Dividends Case Study: Harmony Library, Fort Collins, Colorado. Lighting Research Center. Rensselaer Polytechnic Institute. April.

Brzezowski, E.H., 2008. 31 Tannery Project—Year 2+. www.automatedbuildings.com. December.

CanadianSolar, no date. Discovering BIPV. Project information "cut" sheet. www.canadian-solar.com.

CANMET Energy Technology, 2005. Ground-Source Heat Pump Project Analysis Chapter. RETScreen® International. Natural Resources Canada. www.retscreen.net.

Carnegie Mellon University (CMU), 2004. Implement Underfloor Air Systems to Potentially Achieve 5 – 34% Annual HVAC Energy Savings and 67 – 90% Annual Churn Cost Savings, for an ROI of at Least 115%. Center for Building Performance and Diagnostics. Guidelines for High Performance Buildings.

Center for the Building Environment (CBE), no date (downloaded March 29, 2009). Benefits of Integrated UFAD Systems. University of California at Berkeley. www.cbe.berkeley.edu/underfloorair/benefits_pr.htm.

CBE, 2007. UFAD Field Study of Sacramento Capitol [sic] Area East End Complex. University of California at Berkeley. July 18.

CBE, 2000. Underfloor Air Technology, Frequently Asked Questions. University of California at Berkeley. www.cbe.berkeley.edu/underfloorair/faqs_pr.htm.

Christensen, M., 2007. Great Green: New Air-Conditioning Technology Lowers Costs and

Emissions. State magazine. U.S. Department of State (DOS). September.

Coonen, S., 2007. Building Integrated Photovoltaics. Open Energy Corporation. Presented at the Oak Ridge National Laboratory (ORNL) Solar Summit. October 24.

CTG Energetics, 2005. Simulation Guidebook, Volume 1. Part 1: Underfloor Air Distribution and Thermal Displacement Ventilation. www.energydesignresources.com. June.

Deru, M., P. Torcellini, M. Sheffer, and A. Lau, 2005. Analysis of the Design and Energy Performance of the Pennsylvania Department of Environmental Protection Cambria Office Building. NREL/TP-550-34931. March.

Durkin, T.H. and K.E. Cecil, 2007. Geothermal Central System. ASHRAE Journal. pp. 42-48. August.

Editor, no date (downloaded March 29, 2009). Corporate Center Silver Turns to Gold: Underfloor Air Distribution Plays a Major Role in the Bowie Corporate Center's LEED® Certification Achievement. Commercial Building Products. www.cbpmagazine.com/article.php?articleid=277.

Effert, P. and G.J. Kiss, 2000. Building-Integrated Photovoltaic Designs for Commercial and Institutional Structures: A Sourcebook for Architects. NREL/BK-520-25272. February.

Eley Associates, 2003. Hawaii Commercial Building Guidelines for Energy Efficiency. Chapter 3: Daylighting Guidelines. Department of Business, Economic Development, and Tourism.

Engineered Systems Magazine, 2003. Underfloor Air Cools Renovated Kansas City Roundhouse. www.esmagazine.com. December 18.

Ferrar-Nagy, S. and P. Voss, 2006. The U.S. Environmental Protection Agency's Robert S. Kerr Environmental Research Center, Ada, Oklahoma. Laboratories for the 21st Century Case Study. DOE/GO-102006-2366. October.

Fisk, W., D. Faulkner, D. Sullivan, C. Chao, M.P. Wan, L. Zagreus, and T. Webster, 2004. Performance of Underfloor Air Distribution: Results of a Field Study. Lawrence Berkeley National Laboratory (LNBL) Paper 56257. August 31.

Geothermal Heat Pump Consortium, Inc., 2009. Galt House East, Louisville, KY. GHPC #CS-001. www.GeoExchange.org.

Grabowski, J., 2008a. First Net Zero Electric Commercial Building in the U.S.: 31 Tannery Project. Presented at the federal Facilities Council EISA 2030 Forum. July 22.

Grabowski, J., 2008b. Back to the Grid (Case Study, 31 Tannery Project). High Performing Buildings. pp. 52-60. Spring.

Green Building Research Center, 2007. Sacramento State Underfloor Air Distribution System. Best Practices. University of California at Berkeley.

Greenheck Fan Corporation, 2005. Project Profile: Capital Area East End Complex Block 225, Sacramento, CA. www.greenheck.com.

Griffith, B., N. Long, P. Torcellini, and R. Judkoff, 2007. Assessment of the Technical Potential for Achieving Net Zero-Energy Buildings in the Commercial Sector. NREL Technical Report TP-550-41957. December.

Haynes, R. and S. Gouchoe, 2008. Current Trends and Challenges in Analyzing Renewable Energy Policy: A Report from DSIRE. North Carolina Solar Center. North Carolina State University. Presented at the NREL Strategic Energy Analysis Seminar. December 11.

Herig, C., 2000. Assessing Rooftop Solar-Electric Distributed Energy Resources for the California Local Government Commission. National Renewable Energy Laboratory (NREL). October.

Hoenmans, A. and O. Van Geet, 2008. Walking the Walk, Case Study—NREL Science & Technology Facility. *High Performing Buildings*. pp. 14-25. Summer.

Horwitz-Bennett, B., 2004. Above or Below? *Consulting-Specifying Engineer*. October 1.

Hue, S., Q. Chen, and L.R. Glicksman, 1999. Comparison Between Displacement and Mixing Ventilation Systems for Different U.S. Buildings and Climates. *ASHRAE Transactions*. Vol 2., pp. 453-464.

Hughes, P.J., 2008. Geothermal (Ground-Source) Heat Pumps: Market Status, Barriers to Adoption, and Actions to Overcome Barriers. Oak Ridge National Laboratory (ORNL)/TM-2008/232. December.

James J. Hirsch & Associates, 2006. eQUEST™ Version 3.6 and DOE-2.2 Version 44. August 21.

Karvonen, A., 2001. The Revolution is Underfoot: Raised Floor Systems are Becoming More and More Popular in Office Buildings Due to Their Flexibility, Energy Efficiency, and Occupant Comfort Characteristics. *Environmental Design and Construction*. January 15.

Kavanaugh, S., no date. Ground-Coupling with Water Source Heat Pumps. *University of Alabama.*

Kavanaugh, S., 2008. Ground Source Heat Pumps for Commercial Buildings. HPAC Engineering. www.hpac.com. September 1.

Kim, I.G. and H. Homma, 1992. Possibility for Increasing Ventilation Efficiency with Upward Ventilation. ASHRAE Technical Data Bulletin. Vol. 8, No. 2.

Koh, B. and M. Nicklas, no date. A High Performance School Case Study: Northern Guilford Middle School. Innovative Design, Inc.

Kozlowski, D., 2006. Using Daylighting to Save on Energy Cost. Building Operating Management. www.facilitiesnet.com. April.

Levy, H.F., no date. Comfort, Sustainability, and Energy Savings Using Moving Air. Argon Corporation.

Lienua, P.J., T.L. Boyd, and R.L. Rogers, 1995. Ground-Source Heat Pump Case Studies and Utility Programs. Prepared for U.S. DOE, Geothermal Division. Oregon Institute of Technology. April.

Loftness, V., R. Brahme, M. Mondazzi, E. Vineyard, and M. McDonald, 2002. Final Report, Energy Savings Potential of Flexible and Adaptive HVAC Distribution Systems for Office Buildings. Center for Building Performance and Diagnostics at CMU and Oak Ridge National Laboratory Air Conditioning and Refrigeration Technology Institute. March.

Loftness, V., P. Mathew, G. Gardner, C. Mondor, T. Paul, R. Yates, and M. Dellana, 1999. Sustainable Development Alternatives for Speculative Office Buildings: A Case Study of the Soffer Tech Office Building. Final Report. April 20.

Lund, J.W., 2005. Geothermal Heat Pump Case Studies of the West. Geo-Heat Center Quarterly Bulletin, Vol. 26, No. 3. Oregon Institute of Technology. September.

Majersik, C., 2008. Greening DC Building Codes (presentation slides). Institute for Market Transformation. www.imt.org/codes. February 20.

McHugh, J., P.J. Burns, and D.C. Hittle, 1998. The Energy Impact of Daylighting. ASHRAE Journal. pp.31-35. May.

Milam, J.A., 1992. Underfloor Air Distribution HVAC Analysis. Environmental Design International. Prepared for USG Interiors, Inc.

Morante, P., 2004. Daylight Dividends Case Study: Smith Middle School, Chapel Hill, N.C. Lighting Research Center. Rensselaer Polytechnic Institute.

Multistack, 2009. Building for the Future—The U.S. Mission to Geneva Goes Green. Corporate Press Release. www.multistack.com. April 12.

National Institute of Building Sciences (NIBS), 2009. Executive Order 13423 Technical Guidance—Daylighting. Whole Building Design Guide. www.wbdg.org/references/mou_daylight.php. Downloaded July 19.

NIBS, 2009. Whole Building Design Guide, EPA Region 8 Headquarters. http://www.wbdg.org/references/cs_epadenver.php. Downloaded June 7.

National Renewable Energy Laboratory (NREL), 2009. PV Watts, version 2 (online software). http://rredc.nrel.gov/solar/calculators/PVWatts/version2/. July 9 (date of simulation).

New Buildings Institute, 1998. Absorption Chillers. Southern California Gas Company, Advanced Design Guideline Series. November.

O'Connor, J., E. Lee, F. Rubinstein, and S. Selkowitz, 1997. Tips for Daylighting with Windows—The Integrated Approach. Chapter 3: Shading Strategy. Building Technologies Program. Lawrence Berkeley National Laboratory (LNBL). January.

O'Loughlin, M., 2009. So You Want to Design a Chilled Beam Systems? *Engineered Systems* webinar. Semco, Inc. May 12.

Pacific Gas & Electric Company (PG&E), 2000. CoolTools™ Chilled Water Plant Design and Specification Guide. Report #CT-016. May.

PG&E, 1999. Daylighting Initiative, Phillip Burton federal Building. www.pge.com/pec/daylight/

Peoples Gas, 2006. Distributed Generation: Photovoltaics. www.peoplesgasdelivery.com/business/

Piette, M. and P. Rumsey, 1998. Memorandum to F. Smothers and G. Starkey re Findings from the Information Monitoring and Diagnostic System (IMDS). Chapter 5: Appendices. October 28.

Pigg, S., 2005. Energy Savings from Daylighting: A Controlled Experiment. Energy Center of Wisconsin (ECW) Report No. 233-1. May.

PRWeb, 2009. Daikin and McQuay Open $50 Million Applied Development Center to Develop Sustainable HVAC Solutions for Markets Worldwide. www.prweb.com/printer/2440674.htm. May 20.

Reliant Energy, no date (downloaded March 29, 2009). Energy Savings Center—HVAC: Underfloor Air Systems. www.reliant.com.

Romm, J.J. and W.D. Browning, 1994 (revised 1998). Greening the Building and the Bottom Line: Increased Productivity through Energy-Efficient Design. U.S. DOE and Rocky Mountain Institute. December.

RS Means, Inc., 2008. Means CostWorks 2009 Software. Release 13.0.

Ruck, N., O. Aschehoug, S. Aydinli, J. Christoffersen, G. Courret, I. Edmonds, R. Jakobiak, M. Kirschkoweit-Lopin, M. Klinger, E. Lee, L. Michel, J. Scartezzini, and S. Selkowitz, 2000. Daylight in Buildings—A Source Book on Daylighting Systems and Components. International Energy Agency, SHC Task Force 21. July 29.

Rumsey Engineers, Inc., 2001. Missouri Department of Natural Resources, Schematic Design Report, HVAC System, DNR Green Office Building. 100% Schematic, Revision 1.1. June 14.

Rumsey. P. and J. Weale, 2007. Chilled Beams in Labs, Eliminating Reheat and Saving Energy on a Budget. ASHRAE Journal. pp.18-25. January.

Sachs, H.M., S. Nadel, J.T. Amann, M. Tuazon, E. Mendelsohn, L. Rainer, G. Todesco, D. Shipley, and M. Adelaar, 2004. Emerging Energy-Saving Technologies and Practices for the Building Sector as of 2004. American Council for an Energy-Efficient Economy Report No. A042.

Spinazzola, S., 2005. HVAC: The Challenges and Benefits of Underfloor Air Distribution Systems. Building Operating Management. November.

Stanke, D. and B. Bradley, 2001. Turning Air Distribution Upside Down … Underfloor Air Distribution. Trane Engineers Newsletter, Volume 30, No. 4.

Tate Access Floors, no date. Underfloor Service Distribution, Johnson County Sunset Drive Office Building, Olathe, Kansas.

Tatum, R., 2003. Picking Panes that Save Energy. Building Operating Management. www.facilitiesnet.com/windowsexteriorwalls/article/Picking-Panes-That-Save-Energy--1635. November.

Ternoey, S.E., 2001. Not Your Father's Daylighting. LD+A, the journal of the Illuminating

Engineering Society of North American (IESNA). January.

Ternoey, S.E., 1999. Daylight Every Building. Daylighting Collaborative/Energy Center of Wisconsin.

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

United States Department of Energy (DOE), 2009. Recover Act Announcement: Secretary Chu Announces Nearly $50 Million of Recovery Act Funding to Accelerate Deployment of Geothermal Heat Pumps. http://apps1.eere.energy.gov/news/progress_alerts.cfm/pa_id=176?print. June 2.

DOE, 2009. Chicago Social Security Administration (SSA) Demonstrates Success Using Utility Energy Services Contracts (UES) and Energy Savings Performance Contracts (ESPCs). FEMP Focus. Office of Energy Efficiency and Renewable Energy. Spring.

DOE, 2008. 2007 Federal Energy Saver Showcase Winners. federal Energy Management Program (FEMP). January 9.

DOE, 2006. Commercial Buildings Energy Consumption Survey (CBECS). Table C1: Total Energy Consumption by Major Fuel for Non-Mall Buildings, 2003. December.

DOE, 2006. Daylighting. Building Technologies Program. June 13.

United States Department of State (DOS), 2009. Cooling System Showcases Cutting-Edge U.S. Innovation in Sustainable Technology: Magnetic Levitation (MagLev™) Chiller First of Its Kind in Europe. http://geneva.usmission.gov/Press2009/0402MagLev.html. April 2.

DOS, 2007. Breakthrough Energy Technology in Embassy Tokyo. Bureau of Overseas Building Operations. www.state.gov/obo. March 8.

University of Hong Kong, no date (downloaded June 20, 2009). Energy Saving Matsushita Electric Industrial Co., Ltd. School of Architecture. Case Studies. http://www.arch.hku.hk/~cmhui/japan/matsushita/mat-energy.html

U.S. Green Building Council (USGBC), 2009. LEED 2009 for New Construction and Major Renovations. Version 3.0. www.usgbc.org/leed/

USGBC, 2007. LEED Version 2.2 New Construction and Major Renovation Reference Guide, Third Edition. October.

Wallace, M., no date (downloaded June 2009). Increase Emphasis on Smart, Energy-Efficient, and Sustainable Building Going Forward. ETI Professionals, Inc. and U.S. State Department. www.state.gov/documents/organization/79048.pdf.

Washington State University Cooperative Extension Energy Program, 2003. Energy Efficiency Fact Sheet—Centrifugal Chillers High Efficiency. WSUCEEP00-138.

Webster, T., F. Bauman, P. Morris, and B. Porteous, 2005. Underfloor Air Distribution Cost Analysis. CBE. October.

Webster, T., 2004. Alternative Air Conditioning Technologies: Underfloor Air Distribution. federal Energy Management Program, New Technology Demonstration Program, Technology Installation Review. March.

Webster, T., F. Bauman, and E. Ring, 2002. Supply Fan Energy Use in Pressurized Underfloor Air Distribution Systems. CBE Summary Report. October.

Whitson, A., 2002. Oversized Systems Hamper Ability to Control Utility Costs. Business Expansion. February 1.

Wilson, A., 2009. Building-Integrated Wind Power a Dubious Technology. GreenSource. May 25.

Wisconsin Public Service Corporation, 2007. Budget—Building Integrated Photovoltaics. www.buildingsolar.com/budget.asp.

Yearout, K. and J. Walleisa, 2007. Lessons Learned: Designing and Building Underfloor Air Distribution Systems. Presented to the U.S. Green Building Council (USGBC) Colorado Chapter. September.

York, a Johnson Controls Company, 2006. Michigan Energy Center Achieves Gold LEED® 2.1 Certification with Help from York® FlexSys™ Underfloor-Air Distribution System. HVAC&R Engineering Profile. www.york.com

Appendix A: Leed-Nc® Credits And Available Points

TABLE A-1: LEED® CREDITS RELATED TO UFAD

Credit ID and Description	Potential Points Available		Comments
	LEED-NC® v2.2	LEED-NC® v3.0	
EAc1: Optimize Energy Performance	(2 – 10)[1]	(2 – 10)[1]	By delivering optimal volumes of air for proper ventilation and thermal space conditioning, implementing UFAD usually result in significant energy savings. Energy savings are often enhanced by one or more of the following complimenting measures: (1) occupant controls; (2) VAV blowers; (3) demand-controlled ventilation (*e.g.*, CO$_2$ sensors and associated feedback controls to the ventilation system); and (4) air-side economizers. *Note: In laboratory environments, it may not always be possible to precisely optimize air flows based on space conditioning, because certain minimum air changes per hour are necessary to ensure compliance with industrial hygiene regulations and guidelines.*
MRc4.1/4.2: Materials Reuse (*MRc3.1/3.2 in LEED-NC® v3.0)*	1 – 2	1 – 2	Many of the components currently used to construct the raised or "access" floors associated with UFAD systems contain up to 30% recycled content.[2] Depending on the relative amounts of pre-consumer and/or post-consumer recycled materials in the construction product, the project may be able to earn points under this credit. Pre-consumer recycled materials count one-for-one based on weight, while post-consumer recycled materials count one half-to-one (*i.e.*, 0.5 lbs of recycled material for every pound of product used). One point is awarded for 5% total recycled content materials (based on cost); a second point is awarded for 10% total recycled content.
EAp1: Minimum IAQ Performance	NA	NA	For this prerequisite, LEED-NC® requires that facilities satisfy the minimum requirements of ASHRAE 62.1-2004 regarding delivery of ventilation makeup air to the building space. UFAD systems aid in achieving the ASHRAE requirements by delivering greater supplies of fresh makeup air to the occupant breathing zone. Specifically, using the Ventilation Rate Procedure (the more common calculation approach for compliance with ASHRAE 62.1), a Zone Air Distribution Effectiveness Coefficient (E$_z$) of 1.2 is assigned for UFAD configurations, compared to an E$_z$ of 1.0 for ceiling air makeup delivery systems. (*Thus, all other parameters being equal, a UFAD system is only required to delivery 83.3% of the CFM of air that an equivalent ceiling-located system would need to, in order to achieve the same level of ventilation effectiveness*).
EQc2: Increased Ventilation	1	1	This credit requires that, for mechanically ventilated spaces, delivery of fresh outdoor air to the occupants' breathing zone be increased by at least 30% above the ASHRAE 62.1-2004 minimum (*i.e.*, 30% greater than the ventilation rate required by EQp1). As discussed previously, one of the key advantages of UFAD is its ability to increase delivery of fresh makeup air to the breathing zone without correspondingly increasing airflow rates, thus allowing installation of a smaller capacity fan-and-duct system (lower first costs) and less powered air movement (lower energy costs).
EQc3.2: Construction IAQ Management Plan, Before Occupancy	1	1	One option available for complying with this credit (Option 2) requires that certain minimum indoor air quality standards be attained prior to occupying the space. These specifically consist of maximum allowable concentrations of formaldehyde, PM$_{10}$, total VOCs, CO, and (in some instances) 4-PCH.[3] The increased conveyance of fresh air through the breathing zone supplied by UFAD systems should, in most cases, improve the project's ability to comply with these standards and hence earn the one point available for this LEED® credit.
EQc6.2: Controllability of Systems, Thermal Comfort	1	1	UFAD systems are often integrated with individual workstation controls, to further optimize fresh air and space conditioning (heat, coolness) to the occupants. To achieve the one point available under this credit, at least 50% of the occupants must have access to ventilation controls (or operable windows if certain criteria for natural ventilation configurations are met).
EQc8.1: Daylight and Views, Daylight 75% of Spaces	1	1	The increase in slab-to-slab height (typically a gain of one foot or more) offered by UFAD systems often allows for better daylighting designs, particularly through introduction of near-ceiling incident light that lights the space without excess solar heat gain.

Appendix A: Leed-Nc® Credits And Available Points

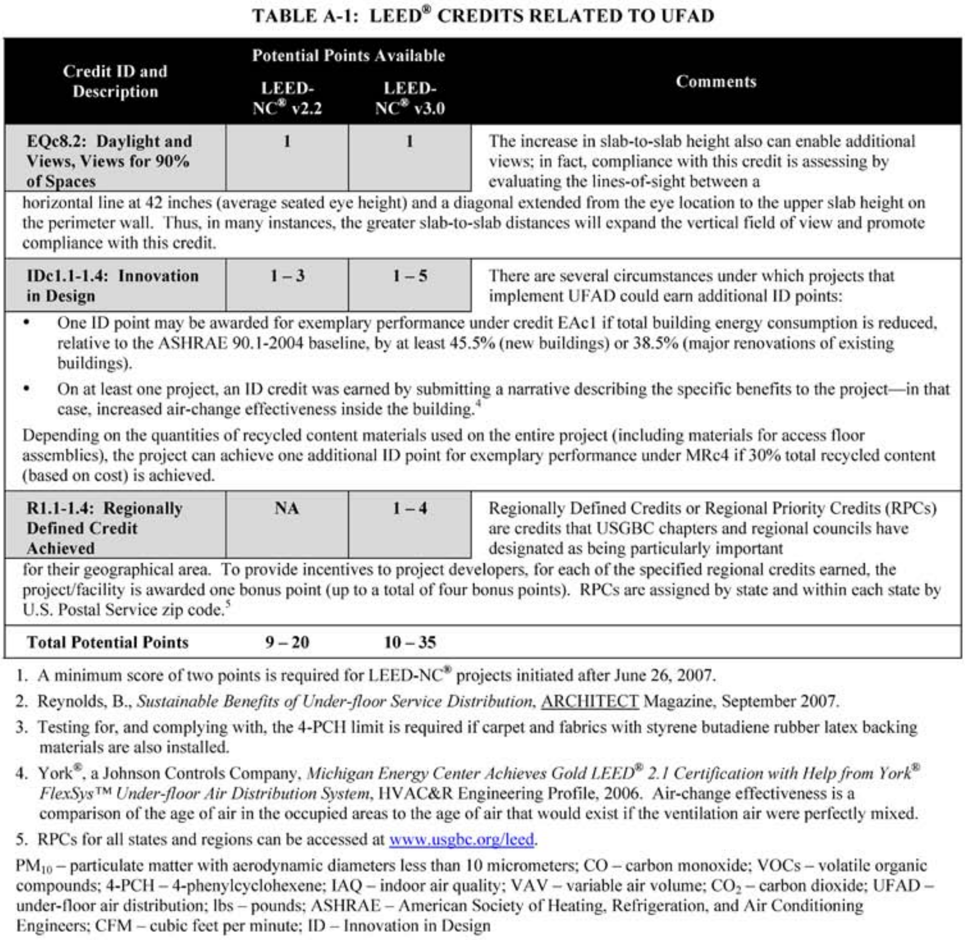


TABLE A-1: LEED® CREDITS RELATED TO UFAD

Credit ID and Description	Potential Points Available LEED-NC® v2.2	LEED-NC® v3.0	Comments
EQc8.2: Daylight and Views, Views for 90% of Spaces	1	1	The increase in slab-to-slab height also can enable additional views; in fact, compliance with this credit is assessing by evaluating the lines-of-sight between a horizontal line at 42 inches (average seated eye height) and a diagonal extended from the eye location to the upper slab height on the perimeter wall. Thus, in many instances, the greater slab-to-slab distances will expand the vertical field of view and promote compliance with this credit.
IDc1.1-1.4: Innovation in Design	1 – 3	1 – 5	There are several circumstances under which projects that implement UFAD could earn additional ID points: • One ID point may be awarded for exemplary performance under credit EAc1 if total building energy consumption is reduced, relative to the ASHRAE 90.1-2004 baseline, by at least 45.5% (new buildings) or 38.5% (major renovations of existing buildings). • On at least one project, an ID credit was earned by submitting a narrative describing the specific benefits to the project—in that case, increased air-change effectiveness inside the building.[4] Depending on the quantities of recycled content materials used on the entire project (including materials for access floor assemblies), the project can achieve one additional ID point for exemplary performance under MRc4 if 30% total recycled content (based on cost) is achieved.
R1.1-1.4: Regionally Defined Credit Achieved	NA	1 – 4	Regionally Defined Credits or Regional Priority Credits (RPCs) are credits that USGBC chapters and regional councils have designated as being particularly important for their geographical area. To provide incentives to project developers, for each of the specified regional credits earned, the project/facility is awarded one bonus point (up to a total of four bonus points). RPCs are assigned by state and within each state by U.S. Postal Service zip code.[5]
Total Potential Points	9 – 20	10 – 35	

1. A minimum score of two points is required for LEED-NC® projects initiated after June 26, 2007.
2. Reynolds, B., *Sustainable Benefits of Under-floor Service Distribution*, ARCHITECT Magazine, September 2007.
3. Testing for, and complying with, the 4-PCH limit is required if carpet and fabrics with styrene butadiene rubber latex backing materials are also installed.
4. York®, a Johnson Controls Company, *Michigan Energy Center Achieves Gold LEED® 2.1 Certification with Help from York® FlexSys™ Under-floor Air Distribution System*, HVAC&R Engineering Profile, 2006. Air-change effectiveness is a comparison of the age of air in the occupied areas to the age of air that would exist if the ventilation air were perfectly mixed.
5. RPCs for all states and regions can be accessed at www.usgbc.org/leed.

PM_{10} – particulate matter with aerodynamic diameters less than 10 micrometers; CO – carbon monoxide; VOCs – volatile organic compounds; 4-PCH – 4-phenylcyclohexene; IAQ – indoor air quality; VAV – variable air volume; CO_2 – carbon dioxide; UFAD – under-floor air distribution; lbs – pounds; ASHRAE – American Society of Heating, Refrigeration, and Air Conditioning Engineers; CFM – cubic feet per minute; ID – Innovation in Design

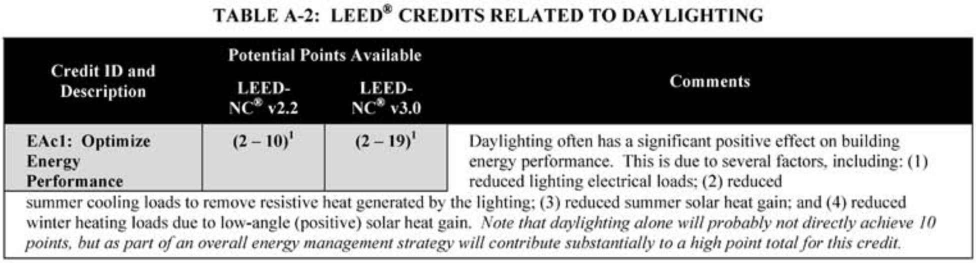


TABLE A-2: LEED® CREDITS RELATED TO DAYLIGHTING

Credit ID and Description	Potential Points Available LEED-NC® v2.2	LEED-NC® v3.0	Comments
EAc1: Optimize Energy Performance	(2 – 10)[1]	(2 – 19)[1]	Daylighting often has a significant positive effect on building energy performance. This is due to several factors, including: (1) reduced lighting electrical loads; (2) reduced summer cooling loads to remove resistive heat generated by the lighting; (3) reduced summer solar heat gain; and (4) reduced winter heating loads due to low-angle (positive) solar heat gain. *Note that daylighting alone will probably not directly achieve 10 points, but as part of an overall energy management strategy will contribute substantially to a high point total for this credit.*

Appendix A: Leed-Nc® Credits And Available Points

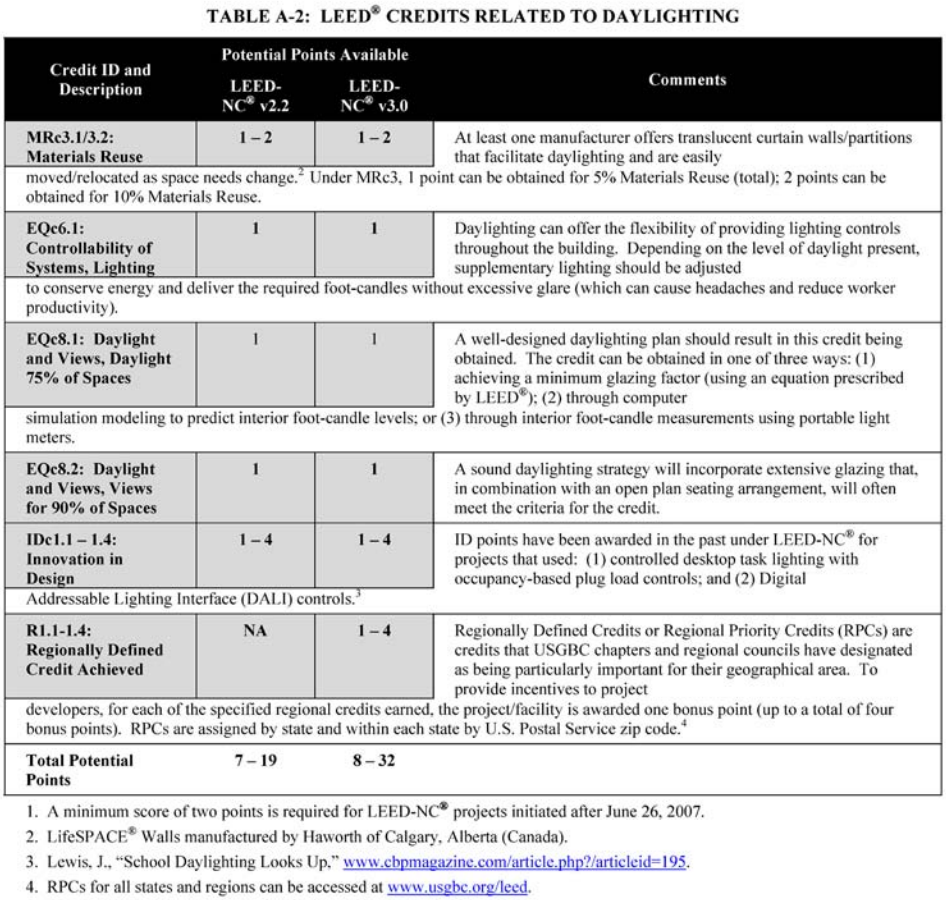


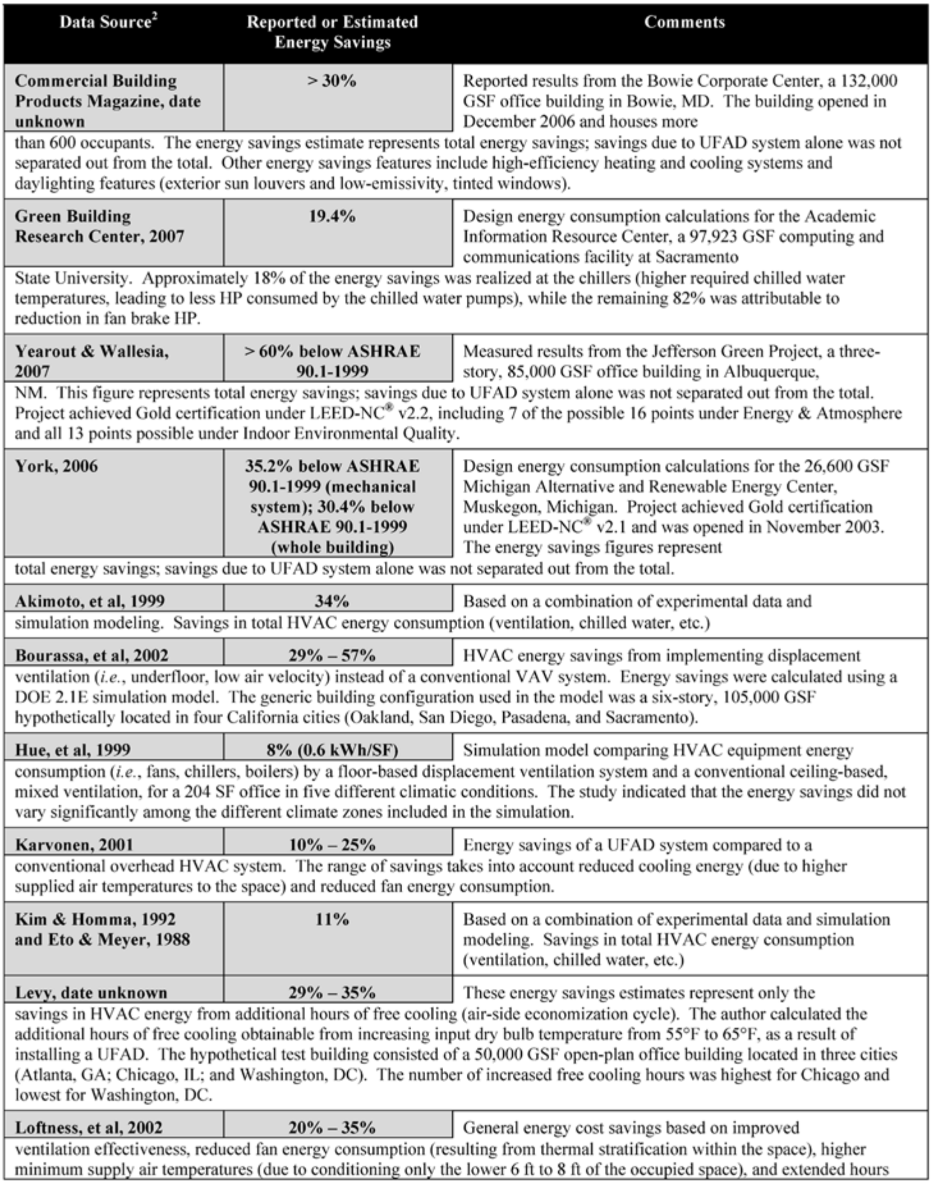
TABLE A-2: LEED® CREDITS RELATED TO DAYLIGHTING

Credit ID and Description	Potential Points Available		Comments
	LEED-NC® v2.2	LEED-NC® v3.0	
MRc3.1/3.2: Materials Reuse	1 – 2	1 – 2	At least one manufacturer offers translucent curtain walls/partitions that facilitate daylighting and are easily moved/relocated as space needs change.[2] Under MRc3, 1 point can be obtained for 5% Materials Reuse (total); 2 points can be obtained for 10% Materials Reuse.
EQc6.1: Controllability of Systems, Lighting	1	1	Daylighting can offer the flexibility of providing lighting controls throughout the building. Depending on the level of daylight present, supplementary lighting should be adjusted to conserve energy and deliver the required foot-candles without excessive glare (which can cause headaches and reduce worker productivity).
EQc8.1: Daylight and Views, Daylight 75% of Spaces	1	1	A well-designed daylighting plan should result in this credit being obtained. The credit can be obtained in one of three ways: (1) achieving a minimum glazing factor (using an equation prescribed by LEED®); (2) through computer simulation modeling to predict interior foot-candle levels; or (3) through interior foot-candle measurements using portable light meters.
EQc8.2: Daylight and Views, Views for 90% of Spaces	1	1	A sound daylighting strategy will incorporate extensive glazing that, in combination with an open plan seating arrangement, will often meet the criteria for the credit.
IDc1.1 – 1.4: Innovation in Design	1 – 4	1 – 4	ID points have been awarded in the past under LEED-NC® for projects that used: (1) controlled desktop task lighting with occupancy-based plug load controls; and (2) Digital Addressable Lighting Interface (DALI) controls.[3]
R1.1-1.4: Regionally Defined Credit Achieved	NA	1 – 4	Regionally Defined Credits or Regional Priority Credits (RPCs) are credits that USGBC chapters and regional councils have designated as being particularly important for their geographical area. To provide incentives to project developers, for each of the specified regional credits earned, the project/facility is awarded one bonus point (up to a total of four bonus points). RPCs are assigned by state and within each state by U.S. Postal Service zip code.[4]
Total Potential Points	**7 – 19**	**8 – 32**	

1. A minimum score of two points is required for LEED-NC® projects initiated after June 26, 2007.
2. LifeSPACE® Walls manufactured by Haworth of Calgary, Alberta (Canada).
3. Lewis, J., "School Daylighting Looks Up," www.cbpmagazine.com/article.php?/articleid=195.
4. RPCs for all states and regions can be accessed at www.usgbc.org/leed.

Appendix B: Energy Savings Data For Ufad And Daylighting

TABLE B-1: ENERGY SAVINGS from UFAD Systems, Literature Review[1]



Data Source[2]	Reported or Estimated Energy Savings	Comments
Commercial Building Products Magazine, date unknown	**> 30%**	Reported results from the Bowie Corporate Center, a 132,000 GSF office building in Bowie, MD. The building opened in December 2006 and houses more than 600 occupants. The energy savings estimate represents total energy savings; savings due to UFAD system alone was not separated out from the total. Other energy savings features include high-efficiency heating and cooling systems and daylighting features (exterior sun louvers and low-emissivity, tinted windows).
Green Building Research Center, 2007	**19.4%**	Design energy consumption calculations for the Academic Information Resource Center, a 97,923 GSF computing and communications facility at Sacramento State University. Approximately 18% of the energy savings was realized at the chillers (higher required chilled water temperatures, leading to less HP consumed by the chilled water pumps), while the remaining 82% was attributable to reduction in fan brake HP.
Yearout & Wallesia, 2007	**> 60% below ASHRAE 90.1-1999**	Measured results from the Jefferson Green Project, a three-story, 85,000 GSF office building in Albuquerque, NM. This figure represents total energy savings; savings due to UFAD system alone was not separated out from the total. Project achieved Gold certification under LEED-NC® v2.2, including 7 of the possible 16 points under Energy & Atmosphere and all 13 points possible under Indoor Environmental Quality.
York, 2006	**35.2% below ASHRAE 90.1-1999 (mechanical system); 30.4% below ASHRAE 90.1-1999 (whole building)**	Design energy consumption calculations for the 26,600 GSF Michigan Alternative and Renewable Energy Center, Muskegon, Michigan. Project achieved Gold certification under LEED-NC® v2.1 and was opened in November 2003. The energy savings figures represent total energy savings; savings due to UFAD system alone was not separated out from the total.
Akimoto, et al, 1999	**34%**	Based on a combination of experimental data and simulation modeling. Savings in total HVAC energy consumption (ventilation, chilled water, etc.)
Bourassa, et al, 2002	**29% – 57%**	HVAC energy savings from implementing displacement ventilation (*i.e.*, underfloor, low air velocity) instead of a conventional VAV system. Energy savings were calculated using a DOE 2.1E simulation model. The generic building configuration used in the model was a six-story, 105,000 GSF hypothetically located in four California cities (Oakland, San Diego, Pasadena, and Sacramento).
Hue, et al, 1999	**8% (0.6 kWh/SF)**	Simulation model comparing HVAC equipment energy consumption (*i.e.*, fans, chillers, boilers) by a floor-based displacement ventilation system and a conventional ceiling-based, mixed ventilation, for a 204 SF office in five different climatic conditions. The study indicated that the energy savings did not vary significantly among the different climate zones included in the simulation.
Karvonen, 2001	**10% – 25%**	Energy savings of a UFAD system compared to a conventional overhead HVAC system. The range of savings takes into account reduced cooling energy (due to higher supplied air temperatures to the space) and reduced fan energy consumption.
Kim & Homma, 1992 and Eto & Meyer, 1988	**11%**	Based on a combination of experimental data and simulation modeling. Savings in total HVAC energy consumption (ventilation, chilled water, etc.)
Levy, date unknown	**29% – 35%**	These energy savings estimates represent only the savings in HVAC energy from additional hours of free cooling (air-side economization cycle). The author calculated the additional hours of free cooling obtainable from increasing input dry bulb temperature from 55°F to 65°F, as a result of installing a UFAD. The hypothetical test building consisted of a 50,000 GSF open-plan office building located in three cities (Atlanta, GA; Chicago, IL; and Washington, DC). The number of increased free cooling hours was highest for Chicago and lowest for Washington, DC.
Loftness, et al, 2002	**20% – 35%**	General energy cost savings based on improved ventilation effectiveness, reduced fan energy consumption (resulting from thermal stratification within the space), higher minimum supply air temperatures (due to conditioning only the lower 6 ft to 8 ft of the occupied space), and extended hours

Appendix B: Energy Savings Data For Ufad And Daylighting

TABLE B-1: ENERGY SAVINGS from UFAD Systems, Literature Review[1]

		during which free cooling (air-side economizer) can be employed (in most climates).
Loftness, et al, 1999	**8.2% (5,150 BTU/GSF)**	Energy analysis of a speculative two-story 64,000 GSF in Pittsburgh, PA, using simulation modeling and information obtained from contractors' bids. Proposed design would have utilized natural gas-fired space heating and electrically-driven, cooling only air handlers equipped with VFDs. The UFAD scenario was compared against a conventional ceiling based HVAC system.
Milam, 1992	**5% (0.95 – 1.55 kWh/SF)**	Simulation modeling of a 26,400 SF "prototypical office building with standard loads," using climate data from Atlanta, GA and Chicago, IL. The UFAD technology was compared to a baseline system consisting of VAV overhead air distribution. Energy savings is, in combination, attributed to several factors, including improved ventilation effectiveness, ability to downsize space conditioning equipment (*e.g.*, chillers), and use of higher set point temperatures due to thermal stratification within the occupied space.
Webster, 2004	**10% – 20%**	Estimated savings in annual HVAC energy usage, which will vary based on the design and on local weather conditions.
Webster, 2000	**48% (fan energy savings)**	Estimated energy savings (specifically associated with fans) of a UFAD system with VAV compared to a conventional overhead system with VAV.
Yearout & Walleisa, 2007	**Up to 40%**	Estimated savings in energy consumption associated with space conditioning (*i.e.*, heating and cooling). A significant contributing factor to energy savings in the decrease in static pressures required to deliver the requisite quantities of fresh air to the various locations (up to 80% of ductwork, a major source of pressure drop, can be removed using open, underfloor plenums).
York, 1992	**15% – 30%**	Savings in HVAC energy consumption.

1. Savings from actual, documented building projects are listed first, followed by other, generalized values presented in the literature.
2. Refer to References List for complete citations.

TABLE B-2. ENERGY SAVINGS FROM DAYLIGHTING, LITERATURE REVIEW[1]

Data Source[2]	Reported or Estimated Energy Savings	Comments
FEMP, 2009	**7% annual energy cost savings ($15,249/year)**	Data is from the Harold Washington Social Security Center (U.S. Social Security Administration), in Chicago, IL. The Center is a 10-story, 693,200 square foot, all-electric office building. The savings resulted from installing lighting controls and dimmable compact fluorescent lamp fixtures in various areas of the facility.
Romm and Browning, 1994	**75% savings in annual lighting energy costs (approximately $500,000/year as of publication date)**	Results from Lockheed Building 157, Sunnyvale, CA, a 600,000-GSF office/engineering design building that opened in 1983. Daylighting features included the following: (1) 15-ft high window walls to enable deep daylight penetration; (2) atrium at the building core that extends from ground floor up to a glazed roof section; (3) exterior light shelves along the south façade; (4) continuously-dimmable fluorescent fixtures with photocell sensors; and (5) separation of ambient and task lighting. *Notwithstanding the substantial energy savings, Lockheed claimed that reduction in worker absenteeism along paid for the $2 million daylighting capital costs within one year of operation.*
PG&E, 1999	**41% and 31% for lighting rows nearest the South and North outer skin of the building; 22% and 16% for next inside lighting rows (South and North); Mid-day peak load was reduced by over 77%**	Phillip Burton federal Building, which houses the federal Courts, and federal agencies (FBI, GSA, etc.) It is a 20-story, 1.45 million GSF office building and was constructed in 1962. The daylighting project consisted of a 180,000 GSF "test bed" areas for daylighting and other advanced lighting measures. Features that contributed to additional daylighting included: (1) operable mini-blinds and solar film to reduce glare and brightness; (2) photocells and occupancy sensors for individual offices; (3) daylight-actuated dimming

Appendix B: Energy Savings Data For Ufad And Daylighting

TABLE B-2. ENERGY SAVINGS FROM DAYLIGHTING, LITERATURE REVIEW[1]

		controls and wide-area occupancy sensors in open-plan spaces; (4) three-lamp parabolic luminaries for T-8 fixtures; and (5) operable task lighting at workstations. Light levels above 50 fc were maintained in all test areas.
Lighting Research Center, 2004	**85% (sunny days); 60% (cloudy and partly cloudy days)**	Smith Middle School, Chapel Hill, NC. Daylighting features and strategies include the following: (1) building orientation on an elongated East-West axis; (2) double-glazed roof monitors (triangular-shaped light access portals on the roof with baffles to forestall glare and photo-sensors/dimming controls); (3) low-e, double-glazed windows along perimeter walls; (4) light shelves; and (5) light-colored, reflective walls and ceilings.
Lighting Research Center, 2004	**36%**	Harmony Public Library, Fort Collins, CO. Daylighting features include: (1) orientation along an East-West axis, with minimal East and West facing windows; (2) clerestory windows with neutrally-tinted glazing and shaded by overhangs; (3) reflective, off-white paint on walls and ceiling; (4) photo sensors, timers, and PLC programmable controls to minimize usage of interior electric lighting. Reported energy savings are based on five weeks of monitoring in April – May 2004.
Lighting Research Center, 2003	**18% – 22%**	TomoTherapy, Inc. Building, in Madison, WI; a 70,000 GSF commercial building that houses medical offices and treatment facilities. Photo sensors and dimming controls serve approximately 12,000 GSF in the building. Other daylighting measures include: (1) low-e glazing on windows with heavy tint to limit solar heat gain; and (2) manually adjustable window blinds. The range of values represents energy savings under cloudy conditions (lowest) and sunny conditions (highest). *Note: Savings were limited, because due to site constrains, the long axis of the building is North-South rather than the preferred East-West.*
Lighting Research Center, 1997	**44% – 63% lower LPD that allowed by ASHRAE/IESNA 90.1**	Sacramento Municipal Utility District Customer Service Center, Sacramento, CA—a 184,000 GSF office building, consisting of four wings and a central lobby. Daylighting features include: (1) South-facing glazing; (2) light shelves; (3) manually-controlled blinds; (4) deep well skylights on top floor in each wing; (5) photo-sensors and dimmers, controlled by an EMS; (6) CFLs for task lighting fixtures at work stations; and (7) a small group of redwood trees that filter sunlight incident to the lobby (while also providing stimulating views). Lower energy savings estimate is based on total connected LPD, while upper estimate is based on actual in-use LPD during core operating hours.
ASHRAE, 2006	**Up to 60%**	Based on energy cost savings. Assumes that solar heat gain from increased absorption of incident light does not counterbalance electric load reductions.
Kozlowski, 2006	**Up to 75% of baseline lighting energy consumption; 10% – 20% of cooling energy associated with lighting heat load**	Energy savings depends on the amount of available daylight, occupancy pattern, and control strategies.
McHugh, et al, 1998	**68.7% savings in lighting energy intensity; 22.9% savings in total building energy intensity**	Conceptual design of a two-story (with attic), 17,400 GSF commercial building designed to be self-sufficient in energy performance (Zero Net Energy building). Daylighting features included: (1) double-pane, low-e windows (R 8.1 center-of-glass) and a window/wall ratio of 17.4%; (2) clerestory windows; (3) interior/exterior specular light shelf with reflective Mylar® film on top surface; (4) horizontal mini-blinds on windows; and (5) T-8 fluorescent lamps with dimmable electronic ballasts. Design lighting levels are 75 fc in offices and 20 fc in corridors.
Ternoey, 1999	**61% lower A/C tonnage; 56% lower installed fan HP**	Hypothetical, daylit 60,000 GSF office building, compared with a standard building of the same square footage (both six stories tall). The modifications introduced for the daylit building were as follows: (1) 50 ft x 200 ft footprint oriented East-West rather than a 100 ft square footprint; (2) increase in floor-to-floor height from 12.5 ft to 13 ft; (3) 100% access to views rather than 50% access to views.
Pigg, 2005	**25% reduction in cooling energy; 3% reduction in fan energy**	Study compared energy consumption in two identical rooms: one with daylighting features and a "control" room. Both 267-SF test rooms were located at the Energy Resource Station near Des Moines, IA. The "daylit" room featured: (1) high-performance window glazings with high

Appendix B: Energy Savings Data For Ufad And Daylighting

TABLE B-2. ENERGY SAVINGS FROM DAYLIGHTING, LITERATURE REVIEW[1]

visible light transmittance but low infrared radiation transmittance; and (2) direct and indirect lighting controlled by photosensors and dimmers. Entire experiment lasted 70 days in three rounds, during the summer, fall, and winter of 2003. The HVAC system was a conventional chilled water loop with hot water reheat and VAV air distribution.

1. Savings from actual, documented building projects are listed first, followed by other, generalized values presented in the literature.
2. Refer to References List for complete citations.

TABLE B-3: ENERGY SAVINGS FROM PROJECTS USING BOTH UFAD AND DAYLIGHTING

Facility (Location)[2]	Reported or Estimated Energy Savings	Comments
Matsushita Electric (Tokyo, Japan)	**30% cooling energy savings**	Nine-story atrium both admits daylight and creates stack effect, encourages airflow and thermal gradient, thus promoting natural ventilation. Manual (in workspace) and automatic controls for UFAD system; automatic controls engage when room temperature wanders outside established comfort limits. Average supply air temperature to occupied spaces is approximately 4°C (7°F) higher than conventional OH system.
NREL Science and Technology Facility (Golden, CO)	**24% energy savings, compared with a conventional laboratory**	Two stories and 71,347 GSF of occupied laboratory space for PV systems research and testing (mechanical room is on the third floor). The facility achieved Platinum certification under LEED-NC® 2.2. The UFAD system is also VAV. Daylighting features include North- and South-facing windows and clerestories and linked automatic dimming and shutoff controls on light fixtures. The original energy simulation predicted 41% annual energy savings; operational data indicated that energy use was 17% higher than that predicted by simulation.
Northern Guilford Middle School (Greensboro, NC)	**35% energy use reduction, compared with ASHRAE 90.1-2004**	School contains 140,000 GSF and serves approximately 950 students. Daylighting features include East-West orientation, overhangs and fins, interior light shelves, high-reflectivity interior ceilings, low-emissivity window glazings, and dimmable fixtures connected with photo-sensors. Ventilation and space conditioning air for the classrooms, media center, and administrative offices are provided by UFAD (UFAD is not used in the gymnasium, auditorium, or dining facilities).
EPA Region 8 Headquarters (Denver, CO)	**68% compared with conventional office building**	Eight-story 248,849 GSF, LEED-NC® Gold office building in downtown Denver. HVAC system includes UFAD air distribution system supply by rooftop AHUs with economizers and a chilled water circulation system with variable-speed chillers. Daylighting elements include a multi-story south-facing atrium, exterior sun shades (20-inch perforated metal with an 11-inch fin), interior light shelves on the south façade, and occupancy sensors on light fixtures.
Pennsylvania DEP Cambria Regional Headquarters (Ebensburg, PA)	**40% below ASHRAE 90.1-2001 baseline design**	Two-story office building containing 34,500 GSF. More interior spaces are served by a UFAD system with manually adjustable, floor-mounted swirl diffusers and ceiling-mounted return air registers. Daylighting features include photo-sensors and dimmable fixtures and ballasts, open plan offices with nearly all fenestration to the North or South, motorized sunscreens on south-facing clerestory windows, light shelves, and high-reflectance ceiling tiles and interior paints. Energy savings is based on 2002 measured energy usage.

Appendix C: Parameter Values For Energy Simulation Modeling

TABLE C-1: PARAMETER VALUES COMMON TO ALL SCENARIOS

Parameter	Units	Assumed Value
Boiler Efficiency	%	80
Boiler Type	NA	Natural gas-fired, natural draft
Building Plan Dimensions	ft	200 x 200
Chiller Type	NA	Electric, centrifugal with cooling tower loop
Cooling Set Point Temperature	°F	76
Cooling System	NA	Chilled water coils
Domestic Hot Water Heating Source	NA	Natural gas-fired; 2,142 kBTU/hr
Electricity Rate Schedule[1]	$/kWh	PEPCO 2009, incremental block, seasonal
Exterior Walls Insulation R Value	ft^2-°F-hr/BTU-in	13
Heating Air Supply Temperature	°F	95
Heating Set Point Temperature	°F	70
Heating System	NA	Hot water coils
Natural Gas Rate Schedule	$/therm	Washington Gas 2009, uniform, seasonal
Net Window Area, Floor-to-Ceiling Ratio	%	50
Number of Stories in Building	NA	10
Operating Schedule	NA	Monday – Friday, 8 AM – 5 PM, 250 day/yr
Perimeter Zone Depth	ft	15
Roof Insulation R Value	ft^2-°F-hr/BTU-in	29
Sensible Heat Ratio	unitless	0.70
Total Building Usable Area	GSF	400,000
Weather Data File	NA	Washington, DC (2009)
Window Height	ft	5.22

1. Add on demand charge, $/month.
2. Add on customer charge, $/month.

MANAGER'S GUIDE TO PREVENTIVE BUILDING MAINTENANCE

Ryan Cruzan

Here's your comprehensive guide for developing an effective preventive maintenance program for any facility. Topics include facility inspection and assessment, effective lubrication practices, commercial roofing repair, indoor air quality management, applicable government codes, standards and regulations, detailed preventive maintenance procedures, and maintenance scheduling. Specific maintenance approaches are examined for more than 100 types of equipment and building components. Also discussed are the economic value of preventive maintenance, management and motivation of the preventive maintenance team, and setting up a computerized maintenance management system (CMMS).

ISBN: 0-88173-619-8

6 x 9, 304, pp., Illus.,
Hardcover
$98

ORDER CODE: 0627

CONTENTS

PART I: CREATING AN EFFECTIVE PM PROGRAM
1 – What is PM?
2 – The Economics of Preventive Maintenance
3 – Getting to Work: Setting Up a PM Program
4 – The People that Do PM
PART II: TECHNICAL INFORMATION FOR PREVENTIVE MAINTENANCE SUCCESS
5 – Lubrication Theory
6 – Maintaining Commercial Roofs
7 – HVAC Systems
8 – Belt Drives
9 – Indoor Air Quality
10 – Paint & Protective Coatings
PART III: SPECIFIC MAINTENANCE PROCEDURES & REQUIREMENTS
11 – Specific Maintenance Procedures & Requirements
Appendix
Index

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Manager's Guide to Preventive Building Maintenance	**0627**	**$98.00**	

② Indicate shipping address:

CODE: Journal 2010

NAME (Please print)
BUSINESS PHONE
SIGNATURE (Required to process order)
EMAIL ADDRESS
COMPANY
STREET ADDRESS ONLY (No P.O. Box)
CITY, STATE, ZIP

Applicable Discount	
Georgia Residents add 6% Sales Tax	
Shipping Fees	**10.00**
TOTAL	

MEMBER DISCOUNTS
A 15% discount is allowed to AEE members.
☐ **AEE Member (Member No.____________________)**

③ Select method of payment:
☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

Make check payable in U.S. funds to:
AEE ENERGY BOOKS

CARD NO.

Expiration date
Signature

④ Send your order to:
AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

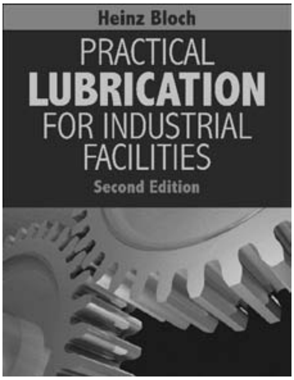
INTERNET ORDERING
www.aeecenter.org

TO ORDER BY PHONE
Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.

PRACTICAL LUBRICATION FOR INDUSTRIAL FACILITIES, 2nd Edition



Heinz P. Bloch

Now completely revised and updated, this book provides those who select and apply lubricants with a comprehensive resource on what products are available, and which lubricants are most effective for specific applications. This new edition expands on the issues of lubricant applications by oil rings (slinger rings) and the elusive problems that often result, and adds a major segment on bearing protector products. The full spectrum of industrial lubricants are addressed, including general purpose oils, hydraulic fluids, food-grade and environmentally friendly lubricants, synthetic lubricants, greases, pastes, waxes and tribosystems. Also examined are lubrication strategies for electric motor bearings, gears, compressors, gas engines and turbines, along with proper lubricant handling and storage, and effective oil analysis.

ISBN: 0-88173-579-5

8½ x 11, 456, pp.,
Illus., Hardcover
Hardcover, $175

ORDER CODE: 0628

CONTENTS

1 - Principles of Lubrication
2 - Lubricant Categories
3 - Lubricant Testing
4 - General Purpose R&O Oils
5 - Hydraulic Fluids
6 - Food Grade & Environmentally Friendly Lubricants
7 - Synthetic Lubricants
8 - Lubricants for Forest Products & Paper Machines
9 - Lubricating Greases
10 - Pastes, Waxes & Tribosystems
11 - Constant Level, Centralized & Oil Mist Lubrication Systems
12 - Bearings & Other Machine Elements
13 - Lubrication Strategies for Electric Motor Bearings
14 - Gear Lubrication
15 - Compressors & Gas Engines
16 - Steam & Gas Turbines
17 - Lube Oil Contamination & On-Stream Oil Purification
18 - Storage Methods & Lubricant Handling
19 - Successful Oil Analysis Practices in the Industrial Plant
Appendix A - Lubrication Program Work Process Manual
Appendix B - Tables, Charts & Factors
Glossary of Terms
Index

BOOK ORDER FORM

① Complete quantity and amount due for each book you wish to order:

Quantity	Book Title	Order Code	Price	Amount Due
	Practical Lubrication for Industrial Facilities, 2nd Edition	**0628**	**$175.00**	

Applicable Discount	
Georgia Residents add 6% Sales Tax	
Shipping Fees	**10.00**
TOTAL	

② Indicate shipping address: **CODE: Journal 2010**

NAME (Please print) BUSINESS PHONE

SIGNATURE (Required to process order) EMAIL ADDRESS

COMPANY

STREET ADDRESS ONLY (No P.O. Box)

CITY, STATE, ZIP

MEMBER DISCOUNTS
A 15% discount is allowed to AEE members.
☐ **AEE Member (Member No.____________________)**

③ Select method of payment:
☐ **CHECK ENCLOSED**
☐ **CHARGE TO MY CREDIT CARD**
☐ *VISA* ☐ *MASTERCARD* ☐ *AMERICAN EXPRESS*

CARD NO.

Expiration date *Signature*

Make check payable in U.S. funds to:
AEE ENERGY BOOKS

④ Send your order to:
AEE BOOKS
P.O. Box 1026
Lilburn, GA 30048

INTERNET ORDERING
www.aeecenter.org

TO ORDER BY PHONE
Use your credit card and call:
(770) 925-9558

TO ORDER BY FAX
Complete and Fax to:
(770) 381-9865

INTERNATIONAL ORDERS
Must be prepaid in U.S. dollars and must include an additional charge of $10.00 per book plus 15% for shipping and handling by surface mail.

Appendix C: Parameter Values For Energy Simulation Modeling

Parameter	Units	Scenarios						
		Base Case	S1	S2	S3	S4	S5	S6
Air Handling System	NA	Multi-zone with reheat	VAV	Multi-zone with reheat	VAV	VAV	VAV	VAV
Average Equipment Power Density[1]	W/ft^2	1.5	1.5	1.5	1.5	0.75	0.75	0.75
Average Lighting Power Density[1]	W/ft^2	1.3	1.3	1.3	1.3	0.9	0.9	0.9
Chiller Efficiency	kW/ton R	0.676	0.676	0.676	0.676	0.56	0.56	0.56
Cooling Air Supply Temperature	°F	55	65	55	65	65	65	65
Economizer Type	NA	Dry bulb temperature	Enthalpy	Dry bulb temperature	Enthalpy	Enthalpy	Enthalpy	Enthalpy
Floor-to-Floor Height	ft	13.5	12.4	13.5	12.4	12.4	12.4	12.4
GSHP Capacity	ton R	NA	NA	NA	NA	NA	NA	1,100 (heating mode)
GSHP Savings – Cooling Load	%	NA	NA	NA	NA	NA	NA	35
GSHP Savings – Heating Load	%	NA	NA	NA	NA	NA	NA	50
Perimeter Zone Photo-sensors	NA	No	No	Yes	Yes	Yes	Yes	Yes
Photo-sensor Design Light Levels	fc	NA	NA	50	50	50	50	50
Rooftop Photovoltaic Array	kW DC	NA	NA	NA	NA	NA	300	300
Variable Speed Drives on Fans and Pumps	NA	No	No	No	No	Yes	Yes	Yes
Window Glazing	NA	Double, clear, ½-in air	Double, clear, ½-in	Triple, low-e, ½-in argon	Triple, low-e, ½-in	Triple, low-e, ½-in argon	Triple, low-e, ½-in argon	Triple, low-e, ½-in argon

TABLE C-2: VARIABLE PARAMETER VALUES, BY SCENARIO

Parameter	Units	Scenarios						
		Base Case	S1	S2	S3	S4	S5	S6
			air		argon			
Window Overhangs	NA	No	No	Yes	Yes	Yes	Yes	Yes

1. In open plan areas, which comprise 70% of the total GSF.

NA – not applicable; ft – feet; °F – degrees Fahrenheit; kBTU/hr – thousand British Thermal Units per hour; kWh – kilowatt-hours; PEPCO – Potomac Electric Power Company; ft^2-°F-hr/BTU-in – square feet-degrees Fahrenheit-hours per BTU-inch; GSF – gross square feet; DC – District of Columbia; VAV – variable air volume; W/ft^2 – Watts per square foot; kW/ton R – kilowatts per ton of refrigeration; ton R – ton of refrigeration, equal to 12,000 BTUs per hour; GSHP – ground source heat pump; fc –foot-candles; kW DC – kilowatts of direct current power, as rated; low-e – low-emissivity