Philadelphia
High-Performance
Building
Renovation
Guidelines
In the same way that integrated design takes teamwork to create a high performance building, so too did the development of these High Performance Renovation Guidelines. Contributing City departments include the Managing Director's Office, Capital Program Office, Budget Office, Department of Public Property, Water Department, City Planning Commission and the Streets Department.

The City's High Performance Building Renovation Guidelines can also be found on the City's website: www.phila.gov.

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Foreword

Foreword from the Managing Director:

I am introducing the City’s High Performance Building Renovation Guidelines as a tool to position City government, with its stock of aging infrastructure, as a leader in sustainable, green building practices. While there is positive movement among building professionals, local governments, universities and other entities to build green and reduce the resource consumption and environmental impacts of traditional design and construction, there is still a large gap between achieving high performance in new construction versus renovation.

Existing green building guides and standards have been applicable in just a handful of new City government construction projects because new construction is a minor piece of the City’s annual capital budget. The focus on renovation makes the City’s Guidelines unique and addresses building practices that affect the quality of life improvements the City seeks to achieve.

The significance of the High Performance Building Renovation Guidelines can be expressed in simple, yet profound ways—building improvements that result in places where people enjoy going to work, where productivity is high, sick days are few, and where cost savings can be channeled to support the delivery of core City services. Your leadership will be required—as a project manager, department head, facility manager, City contractor, or new design team member, you will need to help shed the traditional stovepipe approach to design that separates architect from engineer from contractor from facility manager and so on down the line. Instead, we need dynamic, cooperative design teams that will look at a building as a sum of its parts, a living machine, if you will, that can be designed to operate at an optimal performance level, achieve cost savings and provide environmental benefits.

Your investment in this process will set the stage for citywide opportunities related to green building practices. I envision that the private sector will soon draw upon the City’s building renovation model to renovate office buildings, houses, factories, and other facilities. In this way, the City’s Guidelines can be a catalyst to help transform the vacant infrastructure found citywide into high performing buildings. This trend will also contribute to economic development including, incentives for business to relocate to the City, asset preservation, locally owned and operated green building material manufacturers, and other building sector developments that will increase the City’s economic competitiveness.

Philadelphia is a changing City, and these High Performance Building Renovation Guidelines are a part of the change we seek.

Sincerely,

Philip R. Goldsmith
Managing Director
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Introduction: High Performance Building Renovation Guidelines

Overview
As a nation, we are becoming more conscious of the impacts that building construction and use have on our economy and environment. Building professionals are increasingly using an integrated approach to design that minimizes resource impact, improves efficiency and contributes to worker health and productivity. This trend is often referred to as a high performance, sustainable or green building practice. Achieving high performance building goals in older cities such as Philadelphia is a challenge when a majority of limited capital dollars are stretched to meet the basic renovation and repair needs of aging infrastructure.

A growing number of local governments are adopting Leadership in Energy and Environmental Design (LEED) standards as a way to achieve high performance buildings. LEED is a voluntary rating system issued by the U.S. Green Building Council (USGBC)\(^1\). LEED works best in new construction and major renovation projects where integrated building design provides ample opportunities to gain the credits necessary for achieving a LEED rating. The City is a member of USGBC and the Delaware Valley Green Building Council (DVGBC)\(^2\), and has included LEED standards in most of its new construction and major renovation projects since 2001, including the Police Forensic Science Center (see highlights on page 7), Walnut West Library and Widener Library. These large-scale projects, however, are few and far between, making current LEED standards impractical for use in the majority of typical City capital improvement projects\(^3\).

Further, while LEED establishes goals for sustainability and provides general technical advice, it is not structured to provide specific guidance and detailed discussion on means to achieve these goals.

These High Performance Building Renovation Guidelines (HPBR Guidelines) are structured to focus on typical City renovation projects and provide guidance for considering:

- Renovation sequence;
- Material selection;
- Construction practices;
- Energy use; and
- Operating implications and interrelatedness of building improvements that constitute high performance.

The HPBR Guidelines are designed to help improve the quality of City initiatives in the following areas:

- Energy conservation
- Storm water management
- Recycling
- Waste reduction
- Indoor air quality

The HPBR Guidelines will support the City’s work in newer fields including:

- Climate protection
- Alternative energy sources
- High tech building systems and controls

The HPBR Guidelines are also intended to assist City staff in the planning and budget phases of the capital program process.

Limited capital funds often result in fragmented, and in many instances inadvertent, inefficient approaches to building renovation. The HPBR Guidelines address this problem by including high performance and green building strategies, and by providing a framework in which budget, planning, capital program and department level staff can improve the building renovation process. Use of

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1. USGBC is a not-for-profit organization, with support from both governmental agencies and private sector participants, that is dedicated to promoting sustainability in buildings. See www.usgbc.org for more information.
2. DVGBC is a chapter of USGBC. See www.dvgbc.org for more information, local resources and related activities.
3. A version of LEED for existing buildings (LEED EB) is currently piloted by USGBC. It is probable that LEED EB will need several years to improve and adjust before reaching a usefulness similar that of the current LEED for new buildings and major renovations.
Overview (cont’d)

The HPBR Guidelines will help the City make the most of capital expenditures, increase efficiency, reduce operating and maintenance costs, extend the life of buildings and building systems and reduce the demands placed on the environment in terms of energy and water use, consumption of natural resources, and pollution.

Structure

The Guidelines consist of this introduction plus 12 major renovation project types, each identified as a technical High Performance Building Renovation Guide:

- Guide 1 - Site Issues and Improvements
- Guide 2 - Roof Replacements and Upgrades
- Guide 3 - Upgrading Exterior Walls
- Guide 4 - Windows and Skylights
- Guide 5 - Daylighting
- Guide 6 - Electric Lighting
- Guide 7 - Heating System Upgrades
- Guide 8 – Cooling and Ventilation Systems
- Guide 9 – HVAC Controls and Automation
- Guide 10 - Water Management
- Guide 11 – Material Selection for Sustainability
- Guide 12 - Emerging Technologies

Each HPBR Guide will present the user with design options and material and system selections that will improve building performance and the working environment. Opportunities for achieving an integrated, whole building approach will also be addressed in the “System Integration” section within each technical Guide.

The format of each Guide includes the following elements:

- Terminology
- Role of the improvement
  - Timing/Staging
  - System Integration (opportunities for achieving an integrated, whole building approach)
  - Scale of Importance (from most critical to least critical)
- Sustainable Materials & Systems or Sustainable Strategies (A scale of dollar signs “$” is utilized to provide the reader with a first level estimate of costs as they relate to options within each Guide. The scale ranges from $ to $$$).
- Benefits
- Life Cycle Assessment
- Series Matrix – this section keys-in and cross-references the integrated nature of various technical issues and projects to the series of Guides

Application

The immediate objectives for the HPBR Guidelines are to increase building and operational efficiencies, and to enhance the awareness of design options. The overarching goal is to improve the planning, sequencing and integration of renovation work. By achieving this goal the City will reduce life cycle costs, minimize resource impacts, increase flexibility, and create healthier working environments.

Specific Renovation Projects

Many renovation projects are driven by attention to one building component, such as replacement of a boiler or other type of mechanical equipment. To address projects of such a specific and well-defined nature, all that may be required is to review the appropriate Guide for that component.

Key to such a review, however, will be consideration of the “System Integration” section and of the section on sustainable strategies, or as applicable, on sustainable materials and systems.

Larger-scale Renovations Projects

On larger renovation projects that involve space utilization, it is recommended that an analysis be conducted to assess, select and document the preferred environmental conditions to be achieved in every space. These attributes include access to natural daylight and views, acoustical separation, temperature and humidity requirements, zoning and control of HVAC systems, and needs of sensitive occupants (e.g., people with asthma and infants).
Application (cont’d)

Process Focus

It is not the intention of these Guidelines to provide the precise answers for a particular renovation project. That would be impossible given the wide range of project types. Instead, the Guidelines seek to foster a process that will address questions related to a broad array of design approaches and solutions. This process will allow users to set priorities for higher performance buildings that will better serve the interests and needs of the City and its people.

The user will need to convert the sustainable practices selected from the Guides into design documents and construction practices. The designers and builders are responsible to assess the applicability of any recommendation offered in the Guides, and must apply them as required by the conditions unique to the site.

These HPBR Guidelines are also not intended to supplant the emerging body of green building materials; rather they focus on the needs of older cities to improve opportunities for building performance through renovation work. The HPBR Guidelines user is encouraged to read and use existing green building concepts and materials, including the U.S. Green Building Council Leadership in Energy and Environmental Design (LEED) standards and the Commonwealth of Pennsylvania’s Guidelines for Creating High-Performance Green Buildings. The field of sustainable design and construction evolves rapidly. Even in a more settled area of knowledge, a Guide cannot presume to encompass all useful facts – even less so in this area. Keeping up-to-date is important, probing further when in doubt more so.

Renovation Goals and “Green” Practices

Frequently the scope of renovation projects is set without giving adequate consideration to the key principle of building integration. Consideration of building integration recognizes that the architectural, mechanical, and electrical systems in a building are interdependent. Ultimately, capital planning should take a long-term view of the whole building. Even with limited capital funding, incremental building improvements can result in long-term operating and capital savings.

As the process of renovation evolves from isolated repair and replacement to integrated resource and design practices, the following principles can be applied:

1. Make comprehensive facility investments in the proper sequence.
2. Improve the thermal performance of the building envelope first since these improvements will reduce heating and cooling loads. Replacement of whole central systems should come last in the order of priority.

For example, “weatherization” of the building exterior, such as window replacement or increased roof insulation, reduces heating and cooling loads. High-efficiency lighting upgrades and replacement of fans and motors in air-handling systems may further reduce cooling loads. These improvements should precede or be performed simultaneously with replacement of major heating, ventilating or air conditioning (HVAC) equipment such as boilers. This sequence provides an opportunity to save money by properly sizing building equipment to meet smaller building energy loads.

These HPBR Guidelines seek to raise the quality of building renovations using time-tested methods along with techniques from the “high-end” of today’s building practices. The process may carry the label of high performance, sustainable or green, but the goal is simply to create buildings that work better.

The integrated design process for high performance buildings should achieve the following:

- More efficient use of all types of resources (energy, building materials, water)
- Operations and maintenance cost reductions
- Improved indoor air quality
- Budgets comparable to conventional construction projects
**Renovation Goals and “Green” Practices (cont’d)**

**The Cost of High Performance Renovation**

For most renovation projects, high-performance goals should be achieved without significantly increasing the construction budget. Essential to achieving this goal, however, is a thoughtful and disciplined approach to the design process. Through careful and integrated design and planning it is possible to consider long-term implications of design decisions on changing occupant needs, equipment sizing, and other key factors of performance over the building’s entire life-cycle.

**The Trade-off Approach**

One approach to achieving high performance buildings at costs comparable to conventional construction is through design trade-offs. The idea is that as more sustainable features are integrated into the design (first cost increases), a point is reached where an entire building system, such as the HVAC system, can be downsized or simplified (first cost is reduced back to the starting point).

*Example:* if an office building receives high performance windows, high efficiency lighting, and office equipment with low electricity use, the cooling system can be downsized, reducing the first cost of central plant, and that of ducts, pumps and fans. This reduction in HVAC cost offsets the more expensive windows and lighting (actually, lighting with lower watt/sq ft density often does not cost more than typical design— it only requires a different approach, such as accepting a lower general light level that is supplemented at each workstation by task lighting.)

This technique of trade-offs is usually successful in reducing the cost increase of sustainable features, and if carefully planned, can sometimes result in no cost increase. Keep in mind that not all areas of sustainable design are amenable to trade-offs. For instance, many materials with recycled content do not cost more, but some do. In the latter case, there are no direct savings to be achieved elsewhere. Additionally, where trade-offs can be achieved (e.g., energy, water, waste disposal), programmatic or site constraints may sometimes impede full implementation.

**Other approaches that support no first-cost increases in achieving a high performance building include:**

- **Program changes** - the design team may slightly reduce the building area to accommodate the cost of sustainability (and an area reduction, by itself, is a sustainable action). The team may also change some of the programmatic requirements that are based on conventional design. For instance, a requirement to provide a light level of 50 foot candles (fc) throughout an office building can be changed to a requirement to provide 30 fc general lighting plus task lighting. Similarly, a requirement to provide cooling for 5 watts (w)/sq ft lighting and plug loads in an office building could be realistically reduced to 3-4 w/sq ft, resulting in significant HVAC cost reductions.

- **The starting point is a high-quality building** - many sustainable materials cost about as much as their high-quality counterparts that are not sustainable.

- **The starting point is a very inefficient building with greatly oversized mechanical equipment** - in this case, major reductions can be achieved in the area of mechanical, electrical and plumbing systems.

- **The building occupants accept — and even expect — an extended comfort zone.** For instance, studies have suggested that in buildings with operable windows (where this feature is actually used), occupants prefer a higher temperature during summer, saving energy costs. The effectiveness of natural ventilation in Philadelphia buildings is limited by humidity, so structures occupied by people who are spending much time outdoors (e.g., park structures) are more amenable to this strategy than structures where occupancy is steady and the dress code is more conservative (e.g., office buildings). During winter, occupants feel comfortable at a lower temperature in buildings with low-e windows and well insulated/airtight walls than in buildings with single pane windows and uninsulated/poorly insulated walls.

The discussion on sustainability strategies and cost could fill a book by itself. The purpose of the points above is to highlight the importance of a deliberate plan before proceeding with the sustainability techniques that are covered in detail in the HPBKR Guidelines.
Building Stock
The City of Philadelphia, operates a wide inventory of municipal buildings and facilities totaling over 12 million square feet to serve diverse uses, ranging from recreational facilities to sanitation, from office and government services to correctional facilities, and from police and fire operations to emergency shelter.

Each building type or use serves a set of functions that make its performance unique. Compared to traditional commercial space, municipal buildings have high operating and energy costs. Some of these buildings never close, and many of these buildings were built or put into place (as is the case for some modular, manufactured buildings) prior to the 1970’s when the first world energy crisis led to a need for energy-related codes and standards. Due to the age of much of City’s public building stock, many energy conservation and other environmental opportunities present themselves when renovations are required. In some cases these renovations can restore a building to its former glory. Such is the case in buildings with windows or skylights that were blocked shut during a previous retrofit to reduce heat loss and then opened again to provide daylight and perhaps natural ventilation.

The Planning Process
The HPBR Guidelines provide an opportunity to increase the efficacy and coordination of planning throughout the capital program process. As in most cities, competition for funding facility improvements in the City is keen. Not every project will be funded. Not every project will include all of the high performance features and attributes initially conceived for it. However, if a project is to achieve higher goals than it would under conventional practices, commitment to design objectives must begin during the earliest planning and programming phases. A potential road map for using the HPBR Guidelines as a tool from the inception of a capital program proposal to ultimate funding within a Capital Program year is depicted below:

Requesting Department – use the HPBR Guidelines to help identify, justify and provide staging for projects and subprojects.

Capital Program Office review / Energy Office assistance – use the HPBR Guidelines to check for staging and leveraging opportunities, and use of appropriate technologies, materials, equipment and systems.

Budget Office, City Planning Commission, Administrative and City Council review – use the HPBR Guidelines to support timing and level of project allocations, consider life cycle cost benefits, and understand broader health, energy, environmental and related resource savings.

Outside architects, engineers and contractors – use the HPBR Guidelines to assist in the design process and selection and installation of high performance materials, equipment, systems and other technologies.

Facility Management / Building Services – use the HPBR Guidelines to support operating and maintenance priorities, identify emerging technologies that improve operations and offer maintenance savings, and work with Requesting Departments on identification and staging of projects.

All Parties — use the HPBR Guidelines to support the development of an integrated design approach for the next capital program cycle.

The HPBR Guidelines also provide a mechanism by which the City can create a comprehensive building system inventory and database that will enhance long-term energy analyses, capital program planning, facility management, preventative maintenance planning, service coordination, and system replacement scheduling.

In addition to utilizing the Guidelines in the capital project planning process, other operating and procedural shifts that will help achieve high performing, green buildings include:

- A matching of building program needs and space attributes;
- Timing/staging/ranking of project elements;
- Enhancements to user comfort (thermal, luminous, sonic);
- Access to limited construction funding;
Introduction: High Performance Building Renovation Guidelines

Construction-Related Environmental Concerns

The general green construction practice areas listed below are presented in more detail within technical Guides 1-12, but are listed here to highlight how they are important to the whole building concept:

- Indoor Air Quality
- Importance of Source Control
- Concepts of Material Waste Reduction, Reuse and Recycling during Construction and Demolition
- Other Demolition Concerns: Dust, Noise, Lead, Asbestos, Radon and Mercury
- Design Detailing to Control Moisture, Mold and Tracked-in Pollutants
- Selection of Materials, including earth-friendly fixtures and finishes that withstand public use and are easy to clean, repair and replace
- Construction Activities including Sequencing and Isolation
- Commissioning and Operation of HVAC Ventilation Systems
- Protection during construction
- Concepts and Practicality of “Airing Out” buildings before occupancy
- Housekeeping and Pest Management

High-Performance as a Winning Strategy

Essential to the realization of high-performance buildings, is the creation of "win-win-win" scenarios.

- First, the City needs to affordably build and renovate buildings that cost less to operate and maintain. High performance building first costs must be minimally higher, or where possible, equal to or lower than current building practices. These buildings must be a good economic investment today, as well as for those who will inherit them.
- Second, the benefits of high performance buildings must be apparent to building users in the form of improved comfort, better air quality, and increased access to natural light and views to the outdoors. These buildings must also represent a winning scenario for utilities and others who construct, service and supply the
- • Economic support from applicable programs and governmental initiatives;
- • Integration with current city practices/policies;
- • Cost for incremental conservation improvements/consideration of life cycle savings;
- • Operation and maintenance costs/savings; Reliability and durability

For a project to be successful, realistic and achievable, high performance goals must be established early, and support for the goals must persist throughout the project with respect to performance, environmental quality, and life-cycle economics. Often questions will be asked about construction techniques considered "out of the norm". An educational process will ensue. A project succeeds when the "buy-in" is achieved from all the interested parties including the architect, engineer, construction manager, facility manager and the ultimate users of the space.

The design process should recognize the synergistic nature of potential investments. For example, energy-efficient design strategies to improve comfort and reduce heating and cooling loads have impacts that will last the life of the building. In contrast, some other potential investments such as those related to equipment efficiencies should be evaluated with an eye toward the expected life of such equipment and the operational assumptions for the building. Moreover, during a thorough design process, consideration will often be given to design ramifications that are not always weighed during decision-making. For example, certain energy efficiency measures may contribute to the potential for condensation in wall assemblies if they are not properly detailed and considered along with the HVAC system. The HPBR Guidelines will bring these types of issues to light.

The Planning Process (cont’d)

High-Performance as a Winning Strategy

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High-Performance as a Winning Strategy (cont’d)

City’s infrastructure with energy and water.

- Third, high performance buildings must contribute to an overall effort to improve the quality of the air outside and global environmental conditions. There should be no losers in upgrading buildings and facilities to achieve higher performance, and in many cases local construction practices will be enhanced.

Many City Departments, Agencies and Authorities are contributing to these goals and the collaborative effort has resulted in high performance design for new construction and major renovation projects using the US Green Building Council’s Leadership in Energy and Environmental Design (LEED) standards. Widespread use and support of the HPBR Guidelines will extend success to an ever increasing number of City renovation projects.

High-Performance Renovation — Project Spotlight

Police Forensic Science Center (PFSC)
The City’s first comprehensive, high performance green building, the Police Forensic Science Center, opened in October 2003. Highlights from the PFSC project are detailed below:

The new Forensics Science Center for the Philadelphia Police Department designed by Croxton Collaborative/Cecil Baker & Associates, is a state-of-the-art forensics laboratory facility, and the first ‘Green Building’ for the City of Philadelphia.

The rigorous program includes a Criminalistics and DNA laboratories for hair/fiber/blood analysis; Chemistry laboratories for drug analysis; Crime Scene Unit for 24/7 crime scene evidence gathering; Firearms Unit including a ballistics analysis shooting range. The building is housed in a previously vacant 1920’s Art Deco public school building (1), providing an ‘uplift’ to the local community of North Philadelphia.

Some of the project’s sustainable features include:

- Precise mapping of areas requiring 100% outside air to minimize HVAC loads.
- Pressure mapping of all areas.
- Envelope upgrades resulting in a highly-insulated building.
- “Clean” products and finishes resulting in significantly improved indoor air quality.

This high level of performance has been accomplished for a budget that is more than 20% below the regional average cost per square foot for a Forensics Lab. Computer-based energy analyses predicted greatly reduced energy cost when compared to a typical laboratory that would meet the requirements of the ASHRAE Standard 90.1-1999. The reduction in energy use was estimated to have a payback below 3 years and, in addition to the monetary benefits, will result in significant decreases in pollutant emissions (CO₂, NOₓ, SO₂).

1 Courtesy, Croxton Collaborative Architects, P.C., Reuse of existing school building—Art Deco features retained

2 Courtesy, Croxton Collaborative Architects, P.C., Project sketch featuring daylighting elements
Key:
1. Reactivate regional rail stop at Spring Garden Street
2. Introduce pervious paving @ lighter use areas
3. Outdoor "room" - staff/public area
4. Roof top photovoltaic units/staff conference area
5. Express natural stream course through paving

3 Courtesy, Croxton Collaborative Architects, P.C., Site considerations
High-Performance Renovation: Site Issues and Improvements

The Role of Site Issues and Improvements

Site, as defined for these guidelines, is a building’s property excluding the building footprint. Typical site features include driveways, parking, landscaping, and land set aside for conservation. This guide focuses on site planning issues that directly affect energy use, resource use, stormwater management, and pollution prevention.

Timing / Staging

During Schematic Design, a building and its site can be designed for advantageous acceptance of solar gain (more in winter than in summer) and for daylight penetration.

Management of stormwater via detention, infiltration or irrigation, on-site waste water treatment, and the installation of separate greywater and blackwater waste lines are all best considered starting with the Schematic Design stage, in conjunction with site issues. (Currently in Philadelphia, variances/approvals for waste treatment and line separations options are required).

System Integration

Daylight and Solar Gain

As noted in the Cooling and Daylighting Guides, buildings ideally accept solar gain in winter, are shaded from it in summer, and do not have perimeter spaces affected by glare during occupied hours. Landscaping outside of the building can help achieve these goals in a cost-effective manner that also provides outdoor amenities.

- Evergreen trees planted in front of west and possibly east glazing can block glare during winter months when the sun is low.

- Deciduous trees block 80-90% of sunlight in summer while only 20-40% in winter, after they have lost their leaves. This makes deciduous trees particularly appropriate for south-facing fenestration.

- A trellis with creeping vines can be an effective shading device.

- For sites with winter winds and summer breezes from consistent directions, trees can create a buffer against the former, without impeding the latter.

Terminology

Albedo: The measurement of a material’s reflectance. Light-colored roof surfaces (high albedo) reflect solar radiation, reducing cooling loads or decreasing indoor temperatures.

Blackwater: Waste water from toilets and urinals.

Cut and fill: The removal and replacement of land matter to alter the contours of a site. Associated most typically with the flattening of a construction site for building, road and parking development.

Erosion: The process by which earth is worn away and transported elsewhere by natural forces (forces are subject to acceleration by human activities.)

Greywater: Any water that has been used in the home, except toilet water (e.g., dish, shower, sink and laundry).

Heat island: Developed area that experiences higher temperatures during the cooling season in comparison to adjacent areas, usually based on materials that absorb most of the solar heat (materials with dark surfaces) and/or that cannot quickly radiate the heat (low emittance surfaces). Examples include dark roads and certain dark roofing materials. Some light-colored materials, such as galvanized steel, also promote heat island effects because they retain much of the solar heat (they have low emittance).

Human-induced eutrophication: The process by which excessive plant nutrients accumulate in streams and lakes, promoting algae blooms. These blooms block sunlight from reaching aquatic grasses and deplete oxygen levels in the water, asphyxiating fish and other aquatic life. Two major sources of plant nutrients from human activity are leaching septic systems and lawn and agricultural runoff.

Sedimentation: The accumulation of soils in water bodies by natural forces. (These forces may have been advanced by human activities.)

Solar gain: Heat gain from sunlight.

Stormwater: Rainwater that runs off roofs, parking lots, streets and other impervious surfaces.

1. Much of the discussion to follow is based on LEED, a nationally recognized green building rating tool developed by the U.S. Green Building Council (USGBC), and SPIRIT, the sustainable project rating tool of the U.S. Army Corps of Engineers. Both LEED and SPIRIT include additional credits related to the selection of a site which are not addressed by these guidelines (e.g. land that is not particularly ecologically valuable or sensitive, infill, brownfield, close to public transportation, etc.).
The Role of Site Issues and Improvements (cont’d)

Stormwater Practices

Captured stormwater can be used for irrigation, for cooling tower make-up water, for toilet flushing, etc. This strategy reduces the amount of water discharged from the site while also conserving water resources (currently in Philadelphia, variations/approvals are required to implement a stormwater or greywater reuse strategy).

Scale of Importance

1. Develop the site to enhance the building’s performance in terms of environmental amenities, i.e., solar heat gain, daylight, wind, breezes, views and site use. Do not adversely affect adjacent sites.

2. Reduce stormwater runoff and soil erosion. Strategies commonly used to achieve these goals also reduce the site’s heat island effect.

3. Minimize the need for landscape maintenance, such as irrigation, fertilizer, pesticides, and even lawn cutting by planting a diverse arrangement of native/acclimated vegetation. This vegetation has evolved to resist on local soil conditions and rainfall, and is less susceptible to insect infestations and disease.

4. Use environmentally preferable materials.

5. Reduce light pollution from park sites, and if advantageous, also from urban sites.

6. To the extent possible, encourage the use of public transportation by facilitating access and providing amenities.

Sustainable Site Strategies

Maintain natural site features ($$–$$$

Develop the site within the confines of its natural contours to limit the import and export of soil type, insects, and weeds, while also maintaining natural drainage patterns. Many renovation projects are located on sites that have already been altered, in which case the focus may shift to reintroducing native plants and enhancing rainwater infiltration on site.

Reduce stormwater runoff and associated nonpoint source pollution ($$–$$$

Attempt to decrease the stormwater runoff by at least 25% on developed sites that are more than 50% impervious (1), and not to increase it on sites with better permeability (see EPA’s “Best Management Practices of the Office of Wastewater Management” for more information). The runoff picks up automobile pollutants, pesticides, fertilizers and animal feces, polluting an accepting water body with excessive nutrients. This leads to eutrophication and ultimately aquatic death.

Examples of stormwater practices include:

- **Collection and storage of rainwater** - Rain barrels and cisterns can capture and store roof runoff. Collected water can be used for irrigation, cooling towers, laundry, toilet flushing, and other non-potable cleaning and cooling uses within a building (at this time a variance is required to disconnect a roof leader from the sewer system and connect it to a rain barrel or cistern).

- **Green roofs** – Vegetated systems can be installed on top of existing roofs, to primarily reduce stormwater runoff and minimize the urban heat island effect. Green roofs have other beneficial effects: They protect the roof membrane from UV radiation and reduce the temperature swings, thus extending the life of the membrane. They also reduce, to a small extent, the cooling loads (by shading and evapotranspiration) and the heating loads (by the insulating effect of the additional soil).

  - **Tree canopy** – The leaves, branches, and trunks of trees intercept rainfall, which then evaporates or slowly soaks into the ground, thereby reducing stormwater runoff.

  - **Bioretention/bioinfiltration systems** - If rainwater is not collected and reused, consider enhancing infiltration on site. This recharges groundwater aquifers and 1) reduces the demand on city sewers and waste water treatment plants in combined sewer systems, or 2) in the case of dedicated storm sewer systems, reduces water pollution associated with stormwater runoff. These systems are comprised of moderately depressed, vegetated areas with prepared soil sub-bases that facilitate retention, filtration, treatment, and infiltration of stormwater. Plants and ground cover with roots enhance soil permeability. Shallow-rooted ground cover, of which turf grass is a prime example, tends to blanket the soil rather than enhance its porosity.

  - **Infiltration basins** - Basins are designed to hold rainwater while it infiltrates the ground through the basin’s sides. They are generally designed to hold only as much water as will drain in a period of 72 hours, to avoid mosquito breeding and odors associated with standing water.
Sustainable Site Strategies (cont’d)

Other system designs to minimize or eliminate standing water onsite include subgrade reservoirs that provide underground storage until the water has time to infiltrate into the soil.

On larger sites, consider integrating infiltration basins and other structural amenities, such as a small pond along a walking path.

If soils are not suitable for infiltration, detention is a better solution, particularly in combined sewer areas. Underground detention can be used on sites with limited space for surface storage.

- **Porous paving** (2)- use where a structural surface is required for emergency vehicle access, parking or pedestrian traffic. Systems include:
  - 100% recycled plastic grid embedded under grass, suitable for fire truck lane or seasonal parking.
  - 100% recycled plastic grid embedded under gravel, for wheel chairs or parking.
  - Interlocking concrete pavers with reveals filled with gravel for water penetration.

The durability of a porous paving system comprised of pavers depends greatly on the composition and depth of its sub-base.

- Porous asphalt, consisting of gas-graded aggregates in asphalt binder with interconnecting voids that reduce noise and accidents caused by sitting water and ice. Most of these systems will clog with sand and gravel over time, at which point grass, gravel and paver systems can be deconstructed, cleaned, and re-installed. Porous asphalt should not be installed in areas that receive high sediment loads, and sand and gravel should not be used on porous asphalt during snowy or icy conditions. Additionally, the clogging of porous pavement can be minimized with routine maintenance such as vacuuming and/or power washing.

**Control erosion and sedimentation ($$-$$)$

- **During construction** - reduce erosion by seeding fast growing grasses and/or stabilizing the soil with a cover of hay, grass, woodchips, straw or gravel. Reduce clogging of sewer drains and sedimentation of neighboring water bodies by installing sediment traps and silt fences at appropriate locations.

The City and the State of Pennsylvania require permits and Erosion and Sedimentation (E&S) Control Plans for some types of projects. The Pennsylvania Depart-}

**Stormwater treatment ($$$)**

Sand filters and other structural best management practices (BMP) (3) are installed underground and can eliminate most suspended solids and some of the total phosphates from the stormwater discharge. Off-the-shelf sand filters can be procured as packages for areas of 1.5 to 2 acres. Filters can also be custom-made, following EPA guidelines. Examples include the Delaware model filter (about one acre) and the Washington D.C. model filter (about 5 acres).

**Plant native and acclimated species ($-$-$)**

In combination with physical pest barriers and sustainable construction management practices, planting a diverse landscape of native/acclimated plant species should substantially reduce, if not eliminate, the need for chemical pesticides, fertilizers, and irrigation. This saves money and improves the health of neighboring wildlife and water bodies.

Vegetated stormwater management systems such as bioretenion/bioinfiltration systems are typically planted with native shrubs, trees, and groundcover.

**Reduce heat islands ($$$)**

In addition to promoting water infiltration, rooted plants and porous paving offer the added benefit of keeping the site cool. Asphalt paving absorbs
Sustainable Actions for Sites (cont’d)

heat from the sun and radiates it to buildings, increasing cooling loads. In summer, this paving can make the site uncomfortably hot, and, in combination with the many other paved and dark surface areas in the city, negatively influence local weather patterns. The following strategies have been shown to reduce the heat island effect:

- Use light-colored (high albedo) paving materials in substitution for black asphalt.
- Use pervious paving in substitution for impervious paving.
- Surround and interrupt paving with vegetation, and shade with trees.
- Avoid large expanses of paving by constructing multistory or underground structures for parking.
- Create or maintain water bodies around the building that cool through evaporation. As a vessel for rainwater collection, water bodies can be an integral part of a stormwater management and irrigation system.
- For roofs, refer to Guide #2, page 4.

Reduce impacts from automobile use ($$-$$$)

Transportation with single-occupancy vehicles creates well-documented problems in all cities: congestion (a factor in decreased productivity and lower quality of life), atmospheric and water pollution, and strain on resources. Alternative modes of transportation can be encouraged through provisions such as the following:

- Provide only as much parking as is strictly required. Make alternative transportation convenient and accessible.
- Provide access to bicycle racks, lockers and changing/shower facilities, either in the building or nearby. Provide bicycle lanes in parks and where streets permit. Alert vehicles to bicyclists’ right of way with signs and street markings.
- Provide covered areas for occupants awaiting carpool rides or buses (if applicable). The area should be connected to the building with a covered or protected walkway. Consider how vehicles will be able to stop, and even wait for a few minutes, in order to pick up building occupants.
- Establish a shuttle service to train stations, if beyond a short walk away.
- Designate preferred parking spots for use only by vehicles that arrive with a carpool.
- Consider installing refueling or recharging stations (4) for projects where the building program can support a fleet of alternative fuel vehicles (e.g., electric, bio-gas; for construction equipment, ultra low sulphur diesel, bio-diesel). Renewable energy powered re-charging stations are preferable to those tied directly into the grid.
- Consider car sharing programs as a fleet reduction measure (5).

Use environmentally preferable products ($$$-$$$$)

The following products offer lower toxicity, lower maintenance requirements and/or higher recycled content than conventional alternatives. The list below refers to site work and is not exhaustive.

- Paving and surfacing - for high traffic and other areas where porous paving is not an option consider:
  - Rubber asphalt: Use asphalt that contains rubber pellets from recycled car tires where black top is required. Benefits include:
    - 50% less asphalt cover required.
    - Less prone to rut and cracking under freeze and thaw conditions.
    - Increased friction resistance for better breaking, especially under wet conditions.
    - 3 - 10dB increase in sound absorption.
    - Incorporates a recycled product.
  - Asphalt is also available with recycled glass and recycled ground asphalt.
  - Road Oyl (proprietary): A natural alternative to asphalt, the amber-like substance binds soil and/or aggregates into a monolithic and impervious surface. The resultant paving costs less than asphalt and precludes petrochemical leaching into rainwater runoff.

- Concrete pavers with recycled glass sand and flyash: Concrete hexagonal pavers that incorporate flyash and sand made of recycled glass, for a total 65% post consumer recycled content. Price is competitive with conventional concrete pavers.
  - Poured recycled rubber surfacing with EPDM wear layer for playgrounds.
  - Recycled tire rubber surfacing for indoor and outdoor tracks: 70% recycled content.
  - Crushed waste bricks: Suitable for flower beds, the chips come in 3 sizes: small (1/4-3/8-inch chips), mid (1/2-3/4-inch) and large (7/8-1 ¼-inch).

When using alternative impervious surfaces consider the following stormwater management practices:
- Grade the surface so that the runoff flows to a vegetated area, bioretention area, or
Sustainable Site Strategies (cont’d)

- other stormwater management system.
  - Create an infiltration field under a parking lot or other impervious surface that is fed by a system of distribution pipes.

• Structure
  - Concrete with flyash/steel slag: The Portland cement in concrete can be replaced with flyash, which is a byproduct of coal-burning power plants, or with ground granulated blast furnace slag, which is a by-product of steel production. Beyond reducing the use of cement, a material with extremely high embodied energy, flyash and steel slag increase the structural strength of the cured concrete, while decreasing the concrete’s permeability and bleed channels.

  The latter quality makes the concrete more resistant to pollutants like mild acids, soft water (pulls out lime) and seawater, and less reactive with sulfates (which lead to pitting and cracks from expanding compounds within the concrete and efflorescence).

  Small percentages of flyash/steel slag in the 10 to 20% range are most common. Although the benefits are lower in these percentages, the curing time is relatively similar to flyash-free concrete. High-volume flyash/slag concrete could take twice as long to cure as flyash-free.

  - Glasscrete: Concrete tables, planters, paving stones, and retaining wall blocks manufactured with post-consumer glass cullet.

  - Natural and nontoxic concrete release agents: The most benign release agents are based on agricultural oil (e.g. soy, rapeseed, etc.) and are petroleum-free. They have very low toxicity and VOC content. Agricultural-oil based release agents are about 30% more expensive than petroleum-based released agents, and require a longer lead time for ordering.

    These benign release agents can replace the petroleum-based release agents, such as low-viscosity plain oils, engine oils, mixtures of diesel oil and used engine oil, etc, that often contain heavy metals and toxins, including polychlorinated biphenyls (PCBs).

  - CCA-free wood: Wood pressure-treated with Copper, Chromates and Arsenic (CCA) is suspected to leach chromium and arsenic, two toxic chemicals, into soil around the installation. The wood is also associated with the arsenic poisoning of people cutting and sawing the wood over a prolonged period.

    Alternative wood treatments include Alkaline Copper Quaterrorary (ACQ) and Copper Boron Azole (CBA). ACQ is derived from 100% recycled copper and comes with a lifetime warranty. Wood treated with the product costs about 10% more than CCA-Treated wood. Natural Select™ is less corrosive than ACQ and more brown in color. Wood treated with the product costs between 5-15% more than CCA-treated wood.

  - Ipe Decking (6) also know as Ironwood and other tradenames: This tropical hardwood with natural resistance to rot and pests, is known to last 20 years with only one treatment. To be environmentally preferable, the wood must come from a certified, sustainably-harvested forest (see below).

• Furniture
  - Wood from sustainable sources: Consider salvaged wood or wood harvested in a sustainable manner as certified by the Forest Stewardship Council (FSC).

  - Recycled fiberglass and plastic: Traffic barriers and park furniture are available in recycled fiberglass and recycled plastic.

Reduce light pollution (7) ($$-$$$)

The trespass of light beyond its intended target wastes energy, may cause of glare, can disturb wildlife, and impedes star-gazing in the night sky. Many townships and state commissions throughout the nation have issued recommendations for reducing light pollution. These recommendations include the following:

  - Comply with the illuminance levels and uniformity ratios recommended by the Illuminating Engineering Society of North America (IESNA) Lighting Handbook.

  - Exterior lighting should cover only the intended area.

  - Minimize exterior building lighting; consider employing timers, dimmers, motion sensors and photosensors. Reflectors and other non-lighting alert devices may substitute for some lighting applications.

  - Do not allow artificial light to leave the site. Employ full cutoff fixtures at least along the perimeter and in roadway applications. Install
Sustainable Site Strategies (cont’d)

Benefits

- **Comfort**
  Rooted vegetation — trees, shrubs and groundcover — creates a cooler, better drained site, with greater protection from wind than a site covered in turf grass. Light colored and porous surfaces further reduce the site’s heat absorption compared with impervious asphalt.

- **Energy Savings**
  A cool site contributes to a cool city and a cool building.

- **Reduced Emissions**
  Lower energy use reduces emissions of CO₂, NOₓ, SOₓ.

- **Resource Conservation**
  Use materials with recycled content and divert construction / demolition waste. These actions preserve virgin materials and reduce the size of landfills.

- **Reduced Water Pollution**
  Containing and treating rainwater on site reduces water pollution associated with stormwater runoff and wastewater treatment effluent.

- **Reduced Global Warming**
  Vegetation sequesters CO₂.

Life-Cycle Assessment

A site design that incorporates natural drainage patterns (if remaining) and porous surfacing materials has less need for constructed stormwater drainage paths, underground retention tanks, and hook-ups to the storm sewers.

Maximizing rainwater infiltration throughout the site reduces drainage problems in the spring and ice formation in the winter.

Collecting rainwater for irrigation requires an upfront investment for collecting, storing, filtering, and pumping the water to the sprinklers. Once installed, however, the system saves money.

Additional Information

**Key Words for Internet Searches**
Heat island, stormwater runoff, porous paving, erosion, native planting, light pollution, sustainable harvesting

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High Performance Renovation: Roof Replacements and Upgrades

The Role of Roofs

The goals of this guide are to help you reduce energy costs, particularly heating energy; reduce the size of replacement equipment (such as boilers); and avoid heat-wave related problems in buildings with under or uninsulated roofs.

Roofs are a major (and costly) element in all types of public buildings, both single story and multi-story (1,2). In low-rise buildings, usually defined as three stories and less, roofs comprise a large portion of the building enclosure and are more important than in high-rise construction.

The Introduction discusses building systems within the framework of sustainable renovation. The energy performance of a building depends upon the symbiotic relationship between several systems. In the case of roofs, when it is time to stop fixing leaks and replace the roof, it is also time to 1) improve the thermal performance of the roof; 2) examine roof interaction with HVAC and lighting; 3) assess the effect on comfort and air quality; and 4) consider opportunities for resource conservation.

Timing/Staging

Most roofs have service lives of 15 to 20 years. By then, hard-to-repair leaks might become a major problem. Roofs installed before the mid- to late-1970s likely have little insulation, or have insulation that has become ineffective because of long-term wetting.

Design the roofing system, including insulation amount, before finalizing the selection and sizing of replacement mechanical equipment.

A well-insulated roofing system should be considered early in the renovation process so that systems integration economies can be incorporated into the budget. Not only will this roof protect the rest of the building, but it will reduce heating and perhaps cooling loads, which, in turn, may permit down-sizing of replacement heating and/or cooling equipment.

System Integration

Lighting

A major roof renovation opens the possibility to introduce light into the spaces below through skylights or roof monitors (3,4 on next page). These apertures are created primarily to enhance the indoor environment. For instance, a California study shows that students in classrooms with significant daylighting have better results than students in classrooms with minimal daylighting. As a secondary effect, skylights and roof monitors can reduce energy costs — but only if properly designed (see Guide #5 for recommendations). The energy savings due to roof daylighting are enhanced by integrating the roof apertures with daylight controls for the electric lighting system below.

Size of Heating System

Higher roof insulation can reduce the size of the heating system, especially for low-rise buildings. If the original roof is uninsulated, an upgrade to code-compliant insulation could also reduce the size of the cooling system (check the local codes for current compliance requirements).

But before reducing the size of the heating plant, or of the terminal devices, consider all effects. In old facilities with little or compromised roof insulation, certain spaces retain comfort based on

Terminology

Albedo: Measurement of a material’s solar reflectance. Light-colored roof surfaces (high albedo) reflect solar radiation, reducing cooling loads or decreasing indoor temperatures.

Emittance: Ability to radiate stored heat.

R-values, U-factors: Measurements of insulating value. High R-values and low U-factors provide better insulation.

Roof Monitor: Device at the top of a roof that provides light, and sometimes ventilation, through vertical glazing.

Structural insulated panels: Panels composed of rigid insulation sandwiched between two layers of wood sheathing.

Thermal bridging: Transfer of heat through uninsulated materials, such as steel joists or purlins, reducing insulation effectiveness.
The Role of Roofs (cont’d)

Heat from inefficient lighting systems. If a T-12, magnetic-ballast lighting system is replaced with a T-8 high-efficiency system with electronic ballasts and occupancy sensors, certain spaces that are not continuously occupied could become cold (e.g., conference rooms). This is another reason for upgrading the building envelope before or at the same time with MEP (mechanical-electrical-plumbing) systems.

Stormwater Management
Vegetated (“green”) roofs (fig 9 on page 5) diminish water run-off and, in conjunction with a rain water storage system, could eliminate the need for potable water for irrigation.

Scale of Importance
1. Repair roof leaks immediately (5,6). Water penetration degrades the insulation R-value and damages other building systems (structure, finishes). Leaks can also lead to unhealthy mold growth in the building. Roof service records could indicate the areas that suffered damaging leaks. Infrared thermography can pinpoint where the roof insulation has deteriorated. Insulation in these areas could be in need of replacement.

2. Treat uninsulated roofs. These roofs result in high heating and cooling bills; they can render the spaces underneath uncomfortable or dangerously hot during summer, and can create moisture condensation problems if humidification is provided during winter. Humid air can be generated intentionally, or as part of the activities in the space (e.g., cooking, showers, watering of plants, high occupancy).

3. Increase insulation. Given Philadelphia’s climate, insulation levels 10% - 30% above those required by local code (as part of a complete roof replacement) will typically provide heating energy savings but only modest reductions in cooling energy costs. However, in older buildings with poor insulation, both heating and cooling energy costs will be reduced by higher roof R-values.

4. Provide better ventilation. Building codes require ventilation of unoccupied attics to reduce heat build-up in summer and to remove moisture that originates from the spaces below in winter. Very good ventilation is important for buildings with poorly insu-

Mitigate the urban heat island effect.
Dark colored roofs in dense cities such as Philadelphia can add to local heat build-up or the “heat island” effect that exacerbates hot temperatures during heat waves. Light-colored roofs with high solar reflectance and high emittance (4), as well as planted, “green” roofs (figure 9, page 5) can reduce surface temperatures by 50°F to 60°F. They also decrease the heat build-up in the attic or in neighboring areas during summer. In addition, such cool roofs transfer less heat to the occupied spaces below.
Roof Materials and Systems

This section gives information useful for detailing a roof; but make sure that you account for other aspects that are critical for roof selection, including those discussed in “Life Cycle Assessment” — integration with HVAC, maintenance, and repair. Costs for materials and systems, and their installation, vary according to type (e.g. sloped roof with bituminous shingles vs. flat roof with EPDM membrane) size, disposal of old materials, etc. Check with local roof contractors to get estimates of costs for alternatives.

Install Insulation ($$ - $$$)

**Insulation levels** (consider roofing details such as edge condition and slope when assessing cost-effectiveness).

- **Rigid insulation** for flat roofs of nonresidential buildings is usually cost-effective up to about R-20 to R-25.
- **Fibrous insulation** for attics with wood trusses or with wood joists is usually cost-effective in the R-30 to R-38 range.
- **In roofs or attics** with metal trusses or with metal joists, it is important to cover the metal with continuous insulating sheathing. High levels of insulation between metal members does little good. The most effective detail, from a thermal standpoint, is to place all insulation above or below the metal members (not in-between). Here R-20 to R-25 is usually cost-effective, as with flat roofs. See the discussion on “Roof structures with metal members” below.

In rare circumstances roof insulation thickness should be limited to prevent the “thermos bottle” effect. This can occur in spaces with very high internal heat generation, such as data centers, that are cooling-dominated.

**Insulation types**

- **Rigid insulation** - the type most commonly used for flat roofs is extruded polystyrene (XPS, R-5/inch), because it is fairly dense and does not absorb water. Expanded polystyrene (EPS or beadboard, R-3.8 - 4.4/inch) is less expensive but more easily chipped and, under prolonged exposure, it can absorb water.

The most expensive rigid board tends to be the polyisocyanurate (R-7/inch at installation, R-6/inch aged). Polyisocyanurate is lighter, readily absorbs water and, when wet, is destroyed by freeze-thaw cycles. As a result, it is critical that the roofing membrane be carefully maintained. However, polyisocyanurate has the advantage of providing good insulation with a relatively thin layer. In some cases this is an aesthetic preference and in other cases it is required by existing conditions — such as a low roof curb, or windows or doors that are in close proximity to the roof.

- **Structural insulated panels (SIPs)** - consider wood SIPs for ceilings (7). SIPs are often insulated with polystyrene (XPS or EPS).
- **Fibrous insulation** - usually glass fiber (R-3.1 to 3.3/inch) or mineral fiber (R-3.1 to 4.0/inch fire-proof), used in blankets or batts for attics and cathedral ceilings. Semi-rigid fibrous insulation (R-4.0 to 4.3/inch) is rarely used in pitched roofs because of its relatively higher cost, and even more rarely in flat roofs, because it absorbs water very easily. All fibrous insulation is less expensive per R-value than rigid insulation.

- **Blown insulation** (glass fiber, mineral fiber, cellulose) is typically used in attics. When properly applied, blown insulation is more effective for covering the bottom chords of trusses, or for covering joists (but see discussion below on metal members.)

Polyisocyanurate does not outgas, so it retains its R-value over time; to date it has been used mostly for walls and attics. Because it expands by a factor of almost 100 upon application, polyisocyanure can fill in any holes and crevices in old buildings.

**Insulate Metal Roof Structures ($$)**

Detail roofs with metal structures to reduce “thermal bridging.” Strategies include:

- Placing insulation strips between the top of the metal members and the roof deck;
- Installing insulating sheathing over the entire roof surface, between the metal members and the roofing. This could be achieved with a roof deck and site-applied insulation, or with structural insulated panels (if appropriate for building height and type);
- Insulating the structural metal members that cantilever to form eaves, or supporting the eaves with wood members (possibly attached to the metal structure).
**Roof Materials and Systems (cont’d)**

When detailing metal roof structures examine not only thermal bridging but also the likelihood of moisture condensation. For example, if an attic has metal trusses it is best, from a thermal standpoint, to use continuous insulation below the bottom chord instead of insulation between chords. But if the space below is humidified, continuous insulation below the bottom chord will make this chord even colder. Moisture will be more likely to condense. A possible solution: insulate the top chord of the roof trusses, taking care to also “wrap” any eave extension. The attic becomes a semi-conditioned space, with the truss temperature above dewpoint.

“Green” vegetated roofs (Fig.9 on next page) may be appropriate for some buildings, especially if the roof area is used for programmatic purposes. Green roofs not only decrease the heat island effect, but also decrease storm-water runoff. They have a small, but beneficial effect on heating and cooling. Shallow “extensive” green roofs (approximately 4 inches of soil depth) require little maintenance. “Intensive” green roofs (4 to 18 inches of soil depth) require maintenance relative to types of planting.

**Use Environmental Materials ($ - $$)**

Consider the environmental aspects of roofing systems and component materials.

- Reduced off-gassing: Some single-ply membranes such as EPDM do not contain chlorine or other halogens.

Many rigid-board insulation products (including some of those with the greatest insulating effects) have been produced with ozone-depleting CFCs. Certain polystyrene and polysiocyanurate boards are now manufactured with HCFCs. These compounds affect the ozone layer to a lesser extent. Hydro fluorocarbons (HFCs) are better environmentally because they do not have ozone-depleting potential, however they do present small global warming issues (see Terminology in Guide 8 for more detail on these compounds).

Other manufacturers use Pentane, a flammable water-insoluble hydrocarbon liquid, as an alternative blowing agent. Pentane does not deplete the ozone layer and has a very small global warming effect. It does, however, contribute to smog. Polyicycylene, a recently introduced urethane-type foam, expands through a chemical reaction that forms carbon dioxide. The reaction creates foam without the need for a blowing agent, and thus the insulation is not associated with smog, or ozone depletion, and has a negligible global warming effect. During installation polyicycylene releases ammonia gas, which is an irritant; the gas dissipates quickly with ventilation.

- **Recycled Content:** Metals and petrochemical products form the basis of many roofing systems. Steel roofing products, including sheet and decks, have recycled contents that typically
Roof Materials and Systems (cont’d)

range from 25 to over 60 percent. Copper roof- ing products can have a recycled content of over 70 percent. Certain modified bitumen roll-roofing materials are considered more environmentally benign because they too have significant recycled content.

Several manufacturers use recycled plastics to make shingles that resemble slate and wood. Some metal shingle and panel products employ recycled aluminum and steel, and are available in a variety of colors. These options may be particularly applicable to buildings in Philadelphia’s Fairmont Park.

Use Sustainable Construction ($$)
Consider the effect of roofing application (fumes) on workers and others in dense urban areas.

Divert as much construction waste as possible from landfill. The rating system of LEED 2.1 (Leadership in Energy and Environmental Design) awards one credit for recycling 50% of construction waste, by weight. Bituminous roll roofing and asphalt shingles can be melted and reused as substrate for paving. Roof pavers can be reused, if in good condition, or can be ground and employed as substrate for roads.

Benefits

- Comfort
  For many low-rise buildings the roof surface is a dominant element. Under- or un-insulated roofs transmit heat and cold rapidly. Such a condition can be uncomfortable and even dangerous in the case of over-heated roofs during heat waves. Properly insulated roofs avoid these problems.

  Cool roofs (light-colored or vegetated) avoid the heat island effect, helping preserve more pleasant urban environments.

- Energy Savings
  Substantial heating and cooling energy savings are possible, depending upon building type and operation.

- Reduced Emissions
  More insulation will reduce heating energy use and corresponding site-produced emissions, including CO₂, SO₂, and NOₓ from heating plants.

- Resource Conservation
  Sustainable materials and systems promote conservation of non-renewable resources and can lead to reduced environmental impacts on a global scale.

  Reduction of construction waste, and decreased landfill uses are also important advantages.

- Reduced Water Pollution
  Green (vegetated) roofs decrease storm water run-off.

- Noise Reduction
  Noise is easily transmitted through un-insulated or minimally insulated roofs (particularly metal ones). Green roofs are installed for programmatic use and for many other reasons; noise reduction is a small but real additional advantage.
Life-Cycle Assessment

The true cost of a roof is not only the money invested at the time of construction, but also the ongoing expenditures over the roof’s useful life: maintenance, repairs, energy. Maintenance and repair costs are not easy to predict, but it is better to make an approximate cost estimate than to ignore them.

Account for the effect of the roof on HVAC size when calculating first cost. For instance, the cost for additional insulation could be partially offset by a reduction in the heating plant. Also, when several building systems are renovated in an energy-efficient manner, account for their cumulative effect on heating and cooling equipment. A better roof (e.g. with more insulation and light-colored roofing membrane) may have only a minor effect on chiller size — not enough to allow selecting the next available lower capacity. However, in conjunction with efficient lighting, this roof could trigger a downsizing in cooling equipment.

Maintenance and repair have a strong effect on roof life-cycle cost. Certain roofing types have longer life; some roof insulation types are more tolerant of roof leaks than others.

Example: Extruded polystyrene insulation is unaffected by exposure to water; even in cases of persistent leaks only the roofing membrane needs to be replaced. Polyisocyanurate insulation is vulnerable to moisture. Roof leaks that are not promptly repaired will result in a need to also replace the polyisocyanurate insulation. Greater care must be taken when servicing rooftop equipment, if any. These greater maintenance costs must be balanced against the lower cost for a smaller roof curb. And, for built-up roofing, polyisocyanurate can also result in a lower installation cost. This is because hot bitumen can be applied to the facing of polyisocyanurate, while polystyrene insulation requires protection — typically with a board that is mechanically-attached to the insulation substrate.

In another example of life-cycle cost assessment, a green (vegetated) roof has a significantly higher cost, but it increases the life of the roofing membrane because it protects the membrane from 1) wide variations in temperature and 2) ultraviolet radiation. In addition, the green roof reduces the storm water runoff.

Preventive maintenance using elastomeric coatings extends the life of nonleaking roofs. Applied over a range of roofing types — asphalt, built-up roofing, modified bitumen, metal, wood, single-ply membranes — elastomeric coatings are typically acrylic-based. They’re available in light colors to reduce roofing temperatures, and in air conditioned spaces, to save energy. Elastomeric products can typically extend roof life by 5 to 10 years and longer if recoated at regular intervals, depending on the roofing material. Installed, costs can be as low as $0.85 per square foot for simple coatings, and $2.50 to $3.00 per square foot for a reinforced system (material costs account for about 40-50% of these ranges). Preventive maintenance not only saves money by delaying the need for costly roof membrane replacement; it is also good for the environment because it reduces the amount of construction debris.

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Additional Information

Key Words for Internet Searches
High albedo roofing, thermal bridging, green roof, cool roof, reflective roof coatings
High Performance Renovation: 
Upgrading Exterior Walls

Philadelphia High-Performance Building Renovation Guidelines

The Role of Walls

High-performance exterior walls provide thermal comfort and energy efficiency, and contribute to good indoor air quality. This guide will help you achieve these goals; it also shows how to reduce renovation costs by downsizing the heating system.

Repair, restoration, or renovation of exterior walls presents a rare opportunity that may not occur again for many years or even during the life of the building. It rarely makes sense to engage in retrofit work for the sole purpose of improving the thermal characteristics of the exterior wall assembly. Rather, such an improvement is usually part of a bigger project (e.g., repairing damage, or as part of an architectural modification).

As part of the renovation of a low-rise building, uninsulated walls do not present as great an opportunity for energy savings as uninsulated roofs. With most roof insulation there is no need for 1) additional structure (such as furring for exterior walls); 2) concern about reducing occupied space; or 3) increased concern about fire code restrictions. Of course, both uninsulated walls and uninsulated roofs create discomfort and increase the probability of moisture condensation, so, where possible, it is best to remedy this situation regardless of the energy savings.

In contrast, adding insulation to code-compliant exterior walls offers greater benefits than adding insulation to code-compliant roofs because the code already requires relatively high levels of roof insulation. Exception to this statement: roofs with insulation placed between metal members have as much or more opportunity than exterior walls to improve thermal performance (see Guide #2).

Timing / Staging

Improving the insulation of an exterior wall system should be considered early in a renovation project. The economic effectiveness of this upgrade, and the potential to improve comfort and IAQ, depends, in part, on windows, roofs, and HVAC.

A well-insulated wall provides less benefit unless accompanied by airtight, insulating windows (see Guide #4). A wall brought to code levels should have windows that are at least at code level. Similarly, a high-performance wall, with increased insulation levels, should also have high-performance windows. Where both walls and windows are upgraded, thermal comfort improves significantly and the probability of moisture condensation is greatly reduced.

If the wall is deteriorating or has moisture condensation, it is probably worth considering a wall upgrade. Otherwise, perform a heat loss analysis, combined with a first-cost and energy-cost assessment.

System Integration

Windows and Heating System

To achieve superior comfort and to maximize energy savings, a well-insulated wall needs to be accompanied by a well-insulated window system.

A wall upgrade may be enough to reduce the size of the heating system, but this probability is

Terminology

Air exfiltration: Same as air infiltration, except that air moves from a conditioned space to outside.
Air infiltration: Uncontrolled and unintended air movement from outside into a conditioned space.
Air retarder: Continuous, uninterrupted plane that resists air penetration.
CMU: Concrete masonry unit, a common material in exterior wall construction.
Dew point: Temperature of a surface at which the moisture from air condenses.
IAQ: Indoor Air Quality
Parging: Covering of masonry wall with a coarse layer of plaster
R-values, U-factors: Measurements of insulating value. High R-values and low U-factors provide better insulation.
Spall: Flaking of masonry due to freeze/thaw
Thermal bridging: Transfer of heat through uninsulated materials, such as steel joists or purlins, reducing insulation effectiveness.
Vapor retarder: Sheet with continuous, uninterrupted surfaces that resists water vapor movement.
The Role of Walls (cont’d)

higher if the windows are also high-performance. For example, while higher wall insulation may trigger a reduction in boiler capacity, the size of pipes and pumps might not be affected unless a window upgrade is also undertaken. The heating system is even more likely to be downsized if the roof insulation is also increased.

Similarly, a well-insulated wall will reduce the periods when it feels cold near the building perimeter, but the occupants will not feel truly comfortable unless the windows are at least at code levels, and preferably better. In winter, a person near the perimeter of a building radiates heat toward walls and windows. If these surfaces are cold (as is the case with uninsulated walls, or with single-pane windows), the person feels chilled and, to achieve a measure of comfort, needs warm temperatures in the room – often in the 74ºF to 76ºF range. With better walls and windows, for every 1°F rise in the temperature of the wall/window system, the indoor air temperature can be lowered by 1.4°F without affecting comfort. However, if only the wall insulation is increased, occupants near the perimeter will still feel cold because single-pane windows result in drafts and heat radiation toward the cool window surface. Where this occurs, the indoor air temperature will need to remain high.

Lighting

If the exterior wall system undergoes major repairs, and if the windows are also replaced, it may be possible to consider window systems that promote better daylighting:

- Small windows can be replaced with larger, better insulating windows, to bring additional light into spaces without increased heat loss.
- Large window areas can receive shading devices for protection from direct sun, and light shelves to bounce daylight deeper into occupied spaces.
- Windows that reach to the floor can be replaced with opaque, well-insulated spandrel panels to a height of 2 to 3 feet, provided the aesthetics of the building permit.

Whole-building air-tightness

An airtight building requires not only airtight walls, but also airtight windows and airtight construction for floor slabs, elevator shafts, and walls that separate corridors from regularly occupied areas. See section "Provide Airtight Construction" on page 6 for details.

Scale of Importance

1. Mold growth - a wall with mold growth (1) must be repaired immediately. The effects of mold on occupants can include nasal and lung irritation, allergic reaction and severe sickness that can even lead to death. Common reasons for mold growth are:

- Wet construction materials (e.g., insulation) were placed in the wall.
- Wall was exposed to water while under construction and was closed before drying.
- Wall suffered persistent water penetration after construction, perhaps from a roof leak, faulty exterior finish, leaky pipes, or flooding.
- Wall absorbed water from the foundation, which may have wet conditions for a variety of reasons.
- A wall layer that acts as a vapor retarder is insulated toward the heated space, which is humidified. A typical example is a masonry wall with furred-in fiberglass insulation that is located between masonry and the interior gypsum board. The masonry acts as a vapor retarder – not as good as a polyethylene sheet, but nonetheless quite effective. The masonry surface facing the room is cold, because the insulation is located between it and the gypsum board. If water vapor reaches this cold masonry surface, it will condense and create conditions for mold growth. See discussion under "Exterior Wall Materials and Systems" on page 3 for possible solutions.
- The wall was built, or was later retrofitted, such that its layers act as vapor retarders on both interior and exterior surfaces, and water or water vapor is trapped between these two vapor retarders.
- A wall develops mold after a change in use increases the humidity level. The wall had the vapor retarder on the winter-cold surface of the insulation before, but because the humidity was low, that particular construction configuration did not create problems.
- A wall develops mold after its insulation is upgraded. The most common causes of this condition are:
  - A masonry wall in a humidified space, with insulation placed on the surface of the wall facing toward the room. Alternatively, the exterior finish of the wall could effectively form a vapor retarder (e.g., metal panels), and the insulation is located toward the room.
The Role of Walls (cont’d)

- A wall already drawing moisture from the foundation, or perhaps from a persistent roof leak, that dissipates into the interior space. After renovation, the moisture is trapped at the wall surface and over the long term favors the development of mold.

2. **Breach** - a wall that has a breach in its exterior surface, or at the joints with other systems (windows, roof, foundations) must be repaired immediately, because water damage can undermine its structural integrity and can create mold (see above). In addition, water and air intrusion into the wall decrease the effectiveness of the insulation, creating discomfort and increasing the energy costs.

3. **Insulation** - uninsulated walls should be insulated. An uninsulated masonry wall (2), with plaster finish, has an R-value of about 3.5. By adding 2-inch extruded polystyrene in the wall cavity (3), the R-value increases to about 8. Uninsulated walls result in high heating bills and in discomfort for occupants. If the space is humidified purposefully or incidentally, uninsulated walls may create moisture condensation.

Upgrade insulation in a poorly insulated wall. This can be done in a cost-effective manner if the interior or exterior finishes are replaced for other reasons.

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**Exterior Wall Materials and Systems**

This section presents information useful for detailing exterior walls and accounts for other aspects that are important for exterior wall selection, including those discussed in "Life Cycle Assessment.” Examples include integration with windows and HVAC, maintenance, and repair. Costs for materials and systems, and for their installation, vary according to type (e.g., masonry versus steel stud), size, disposal of old materials, etc. Check with local contractors to obtain reliable cost estimates.

**Install Insulation ($$–$$$)**

**Spaces with humidification** - the first, essential step is to decide on the insulation position in the wall. As discussed in the previous sections, moisture is more likely to condense in a wall if the insulation is located on the winter-warm surface of a wall layer that acts as a vapor retarder. In a masonry wall, the masonry units form an effective vapor retarder. If the insulation is furred-in and placed toward the conditioned space (i.e., on the winter-warm surface of the masonry layer), the masonry surface will become cold. Moisture generated in the occupied space that reaches that cold surface could condense.

- **Exterior insulation** (fig 4 and 5 on next page), where possible, is the best solution for spaces with humidification. A space can be humidified purposefully or as a side effect of its function. Museums and art galleries maintain a certain humidity level during winter using the mechanical system. Some hospital areas and computer rooms are mechanically humidified. Kitchens, restaurants, aquariums, swimming pools and saunas, wet labs, greenhouses, and other spaces generate moisture as part of their activities. Moisture is also generated in apartment buildings when people cook, shower, use humidifiers, etc.

- **Interior insulation** (fig. 6 on next page). If it is the only option, take steps to reduce the probability of moisture condensation:
  - **Create an airtight wall construction**, since most moisture migrates into and across a wall due to air movement. Without air movement, the chance of moisture reaching the cold masonry surface is significantly diminished. See the section "Provide Airtight Construction" on page 6.
  - **Perform a calculation showing the dew point at the masonry surface, at different humidity levels in the room, and at critical outside air temperatures.** It is possible that some insulation levels will provide protection from the cold without unduly increasing the risk of moisture condensation. For example, calculations show that if R-11 insulation is applied to a 12-inch, uninsulated brick wall, moisture will probably condense when the outside air temperature is 25º F and the indoor relative humidity (RH) is 21%. For a museum the RH level would be unacceptable – museums often require 40% RH; for a commercial kitchen the low RH level could be unrealistic; but for a residential building, typical commercial space or a medical...
Exterior Wall Materials and Systems (cont’d)

Exterior Wall Materials and Systems (cont’d)

Exterior insulation is well suited for spaces with massive walls that do not have their temperature lowered at night and during weekends, such as residences. Also, because it is usually more effective in reducing thermal bridging, exterior insulation is often a better thermal solution for buildings with lightweight walls.

Insulation type and position - the amount of cost-effective insulation for wall retrofits depends to a large extent on the position of the insulation within the wall, and on the structure of the wall. It also depends on whether this action will result in a reduction in heating system size. A life-cycle cost analysis is recommended.

- Exterior wall cavity - extruded polyurethane, sometimes abbreviated as XPS (R-5 to R-5.5/inch), is a good choice because it does not absorb water (e.g., from roof leaks or wall defects) and does not lose its initial R-value. Foil-faced polyisocyanurate has higher R-value per inch (R-7 to R-7.5 inch initially, then about R-6 to R-6.5 aged), and therefore provides more insulation for the same thickness. However, polyisocyanurate absorbs water and is destroyed by freeze/thaw cycles if wet. It also has a higher cost per R-value than extruded polyurethane.

- Insulation thickness is constrained by the attachment system for the exterior wall finish. For brick-faced walls, 2 inches of insulation (approximately R-10 to R-11 with extruded polyurethane and R-12 to R-13 with aged polyisocyanurate) can usually be used before having to resort to custom-made, expensive brick ties. The ties create a certain amount of thermal bridging, but the edge of the floor slab has the largest effect on the overall R-value of the wall system. Two inches of XPS rigid insulation conduct heat at a rate of about 0.1 BTU/(hr x °F x sq ft). The concrete in the slab edge conducts heat at a rate more than 50 times higher. Like water, heat prefers the easy path and short-circuits the insulation. The overall R-value of the wall can be reduced by a factor of 2-to-3. In this context, the difference of R-value between extruded polyurethane and polyisocyanurate becomes less important.

- If the slab edge can be insulated to the outside, and

Spaces without humidification - insulation position is influenced by thermal mass. Buildings respond more quickly during warm-up cycles and are more comfortable in the morning when insulation is placed on the inside surface of masonry walls. This is typical of offices used during a 9-to-5 workday.

- If the insulation level is so high that moisture will condense on the masonry surface at typical indoor air RH, it is still possible to reduce this risk to acceptable levels.

Example: In a museum, create an air space between the uninsulated masonry wall and the gypsum board interior finish. Assign an independent airhandler for the interstitial air space. Dehumidify and maintain this space at slight positive pressure with respect to the rooms, so that moist air from the rooms cannot reach the masonry surface.

Carefully consider masonry walls that have furred-in insulation on the winter-warm surface of the masonry (the surface delimiting the conditioned space) and a polyethylene vapor retarder located behind the gypsum board. This construction detail encloses the insulation between two layers that are both vapor retarders: the polyethylene sheet and the masonry wythe. Water must not reach the insulation, or if it does, the situation must be quickly remedied. Otherwise, the water will stay in place and create favorable mold growth conditions. To avoid wetting with liquid water, the wall, roof and windows must be well constructed, so no accidental leakage occurs. The building must be very carefully constructed and maintained to avoid air movement and vapor diffusion from rooms into the wall. This is a difficult task.

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- If the slab edge can be insulated to the outside, and
Exterior Wall Materials and Systems (cont’d)

If the exterior finish does not have to be supported by metal angles, the overall R-value of the exterior wall increases dramatically. This construction type is feasible for low-rise masonry buildings, where the brick facing stands on its own foundation. It is also possible for buildings with lightweight finishes, such as glass or steel. In addition, walls with glass or metal finish can have much thicker insulation, in the 4- to 6-inch range (R-20 to R-36, depending on the material used), because the exterior finish is lighter.

- Pre-assembled wall panels - most have metal or concrete facings.

- Closed Metal Panels - the water absorption drawback of polyisocyanurate is much less important for closed metal panels (those made with two metal faces, or with a glass and a metal face), often making it the insulation of choice for this application.

- Concrete panels - extruded polystyrene (XPS), is often used because it is usually placed during pouring. Expanded polystyrene (EPS), which is lighter, less expensive, and less insulating (R-3.8 to 4.4/inch) is also sometimes encased in concrete panels.

The connections between interior and exterior surfaces are just as important as the insulation R-value. A concrete panel could have R-15 insulation inside but, depending on the method of attachment between the interior and exterior slabs, its overall R-value could be anywhere from about R-5 to about R-12. The variation is even more pronounced for metal panels. In contrast, wood structural insulated panels (SIPs) have much lower thermal bridging because wood is about 300 times less conductive than steel and about 10 times less conductive than concrete.

In buildings without humidification, concrete panels can also be insulated with a steel stud wall toward the conditioned space (7).

- Wood SIPs are composed of a core of XPS or EPS, usually 4 to 6 inches thick, sandwiched between two sheets of oriented strandboard (OSB). They yield a high overall R-value, but their use is restricted to low-rise buildings (structural limitations) and where wood walls are permitted by code.

- Interior insulation - types include rigid, fibrous, blown and sprayed.

- The most common types of interior insulation are glass fiber and mineral fiber. This insulation is usually installed between steel studs at 16 or 24 inches on-center; the stud row is set at least one inch apart from the masonry wall. The studs are 3.5 to 4 inches thick and receive R-11, R-13, and R-15 batts. R-15 batts cost almost as much as R-19 batts, but the R-19 batts are more advantageous, since they snugly fill the gap between studs and wall and do not allow air movement.

The best method to reduce thermal bridging caused by the batts is to install a continuous sheet of semirigid insulation on the wall, between the stud row and the masonry wall. However, another option is construction with 2.5-inch metal studs, which will allow the batts to extend a bit beyond the studs (reducing thermal bridging). This option is also less expensive than construction with thicker studs.

- Semirigid insulation blanket (R-4.0 to 4.3/inch) can be the only insulation used on the inside surface of a wall. For masonry walls, furring is still provided, but the steel stud cavity is left empty to serve as conduit for cabling. If all insulation is placed within the stud wall, as is the case with batts, insulation can be ripped and compressed by wiring. In addition, leaving the stud cavity empty ensures that the insulation is not short-circuited by air convection (i.e., air moving from the room into the wall cavity through receptacles, creating convection loops) that short-circuits the insulation and carries moisture to the cool masonry wythe (assuming that the wall is masonry).
Exterior Wall Materials and Systems (cont’d)

- Insulation can be sprayed in a cavity formed by the interior finish (typically gypsum board) and the masonry wythe (Fig. 8 on previous page). Compare the following:
  - Polyurethane (R-5.6 to 6.3/inch, about 20% lower when aged) and polyisocyanene (R-3.8-4/inch) expand greatly when applied, filling all crevices, including any receptacles left in place. Polyisocyanene is environmentally preferable. Both polyurethane and polyisocyanene release water in the application process, so the wall must be able to dry either to the exterior or to the interior. Check for fire and smoke spread ratings as applicable to the building.
  - Wet-applied cellulose (R-3 to 3.5/inch) does not expand, but it does not release much water. It also has good environmental characteristics (no ozone depletion, no global warming potential).
  - Oxychloride cement (commercially sold as AirKrete) is a very light, fireproof, insulating compound (R-3.9/inch). It can be sprayed either behind a gypsum wall or behind a metal mesh, with the gypsum board mounted subsequently.

- Blown insulation (cellulose, glass fiber) can be used to retrofit wall cavities from inside, without removing the gypsum board, but long-term settling is a concern. Also, voids can remain if the wall has horizontal obstructions between studs.

- Rigid insulation is sometimes used behind the gypsum board to reduce thermal bridging by the steel studs and to add more R-value for a small thickness. Both polystyrene and polyisocyanurate are used, but first check the requirements of the fire code.

- Concrete masonry units (CMU) - insulation can also be located within the CMU in the form of polystyrene inserts, as fill (perlite, vermiculite), or sprayed (urethane, polyisocyanene). The insulation R-value is less important than the shape of the block and the conductivity of the concrete. Ideally, the blocks have webs that are cut in such a way as to reduce thermal bridging caused by concrete. Insulated block R-values are typically in the R-3 to 5 range. To further reduce thermal bridging, the concrete should be of relatively low conductivity. Such products are easily produced, but have to be special-ordered at a higher cost.

Note: All interior insulation, and all insulation within CMUs, is short-circuited by the slab edge, and, for some applications, could also be short-circuited by the steel studs. In general, interior insulation results in a lower overall R-value for the wall than exterior insulation. Refer also to the discussion above on moisture condensation (spaces with humidification).

Provide Airtight Construction ($$ - $$$)

An airtight wall reduces the air infiltration into the space, and thus the energy use. It also reduces the air exfiltration from the space, thus decreasing the likelihood that moisture will be transported into the wall and will condense. Air-tightness does not refer only to air moving across the wall; it also refers to air that moves from the heated space into the wall cavity and then back into the space.

Several methods, with different degrees of effectiveness, can be employed to air-tighten a wall:

- Provide a continuous, exterior air retarder membrane that is bituminous or rubber-based. This membrane is adhered to the masonry layer (for masonry construction) or to the exterior gypsum board sheathing (for steel stud construction). Because the membrane is both vapor and water-impermeable, most or all insulation must be exterior (placed between the membrane and the exterior finish).

- A wall with an air retarder membrane can be designed to have the exterior finish function like a rainscreen (9). For example, the brick finish of a masonry wall is designed to be air-permeable. The bricks have small spaces in between, such as holes or slits. The air penetrates through these holes into the cavity formed between the brick layer and the rigid insulation. Rainwater is not driven into the bricks. It passes through the openings between bricks and seeps down. As a result, the bricks are kept drier, are better protected from freeze/thaw cycles, and are less likely to spall.

- Create a continuous airtight plane to the exterior of the wall by caulking all junctions of a specific layer. For instance, if the construction of the exterior wall is steel stud, caulk all joints of the exterior gypsum board sheathing. If the exterior wall is...
Exterior Wall Materials and Systems (cont’d)

built with masonry and receives exterior insulation, employ tongue-and-groove polystyrene and tape all joints.

- Create a continuous, interior airtight plane. This is difficult to achieve (because there are many wall/floor and wall/ceiling junctions) and also less effective than the exterior air retarder, because outside air might still intrude into the wall, loop around, and get back out again, greatly short-circuiting the insulation. Attempts have been made to achieve a continuous airtight plane by sealing the gypsum board plane and all its penetrations, or by sealing the polyethylene vapor retarder.

- Completely fill the insulation space, so air currents cannot travel within it. This technique impedes air convection from within the heated space and also has a small effect on air infiltration.

- Seal all wall/slab, wall/column, and wall/window joints, and all wall penetrations. This technique also improves fire and smoke spread characteristics, and provides better vermin control.

An airtight wall is very useful in minimizing air movement across and within the wall, but is not sufficient to minimize air infiltration/exfiltration across a building. Windows should also be airtight, and pipes and duct penetrations through floor slabs should be sealed to reduce the amount of air that infiltrates into lower floors and exfiltrates through higher ones (stack effect). Also, build airtight elevator shaft walls and airtight walls between corridors and occupied spaces.

Use Environmental Materials ($$–$$$)

With respect to ozone depletion, global warming and smog, see discussion on rigid insulation board products in Guide # 2. Recycled content. Consider using synthetic gypsum board with 95% to 100% recycled content, and concrete block manufactured with fly ash. Steel studs usually have a recycled content of at least 25%.

Fibrous batt insulation and rigid insulation (10) is manufactured with recycled contents that range between 5% and 50%. Rigid fiberboard has 30% to 80% recycled content.

Reduce Construction Waste ($$)

Separate from the waste stream gypsum board, brick dimensional lumber, fibrous insulation, and rigid boards. These materials can be recycled.

Benefits

- Comfort
  The wall surface is a dominant element in most perimeter spaces. As noted in the "System Integration" section on page 2, the indoor air temperature can decrease by about 1.4°F for every 1°F rise in the temperature of the wall/window system, without affecting comfort. The temperature of the wall/window system increases with greater insulation.

- Energy Savings
  A well-insulated, airtight wall results in significant energy savings.

- Reduced Emissions
  Lower energy use results in fewer CO₂, NOₓ and SOₓ emissions.

- Resource Conservation
  Use of materials with recycled content and diversion of demolition matter from the waste stream conserves natural resources. Construction waste management also decreases landfill use.

- Improved Indoor Air Quality
  Walls detailed to avoid moisture condensation result in healthier environments.

Life-Cycle Assessment

Walls are expensive to build and repair. Design and construction focused on low maintenance results in large lifetime savings. Also, since walls last dozens of years, even modest savings in annual energy costs add up to a significant amount over time. The following components are essential parts of life-cycle cost calculations:

Account for the effect of better walls on the size of the heating system when
calculating the cost of renovation. The cost for additional insulation, or for airtight wall construction, could be offset in part by smaller boilers and furnaces.

• When the windows are simultaneously upgraded, it may also be possible to reduce the size of pipes and pumps.

• When the wall and windows become highly insulating - above code requirements-- baseboard radiation can often be eliminated and all heating can be provided with an air system, without affecting comfort.

Maintenance and repair have a strong affect on the life-cycle cost of walls. Some insulation and air-tightening techniques result in reduced costs over time.

• Exterior insulation protects the slab edge from freeze-thaw damage and keeps most of the wall within a narrower temperature range, reducing the temperature-induced expansion/contraction stresses -- important for masonry construction. Where exterior insulation is coupled with an exterior air/water retarder, the protection from thermal stress is best (see the section "Provide Airtight Construction" on page 6). In conjunction with a rainscreen design, the air barrier also protects the exterior finish from freeze/thaw cycles.

o For a simple application, an air retarder membrane can be installed for about $2/sq ft; airtight planes obtained by taping and sealing existing sheathing or exterior insulation can be achieved at somewhat lower cost.

o Exterior insulation also protects from moisture condenstation. For humidified spaces, this is a very important criterion. Mold remediation is very expensive and is no longer covered by some insurance companies. Moisture condensation can also compromise the wall structure. Given these factors, the additional cost of exterior insulation is more easily justified.

o Extruded polystyrene has lower R-value/inch than polyisocyanurate, but does not absorb water. If a roof leak develops close to the parapet, and if the exterior insulation gets wet, the polyisocyanurate could be damaged; the extruded polystyrene will be unaffected.

• Interior insulation should be selected, whenever possible, to fill the entire furred-in space without leaving air gaps. This technique reduces the likelihood of air intrusion from the heated space into the wall cavity; it also reduces, to some extent, the air infiltration across the entire wall. Thus, over time, there could be a lower chance of moisture condensation. However, in humidified spaces always check to ensure that the interior insulation does not have such a high R-value as to create moisture condensation.

• Insulation integral to concrete masonry units reduces the conduction heat flow through the wall. However, CMU walls can also lose heat through convection. If the CMU layer is left without parging (a typical situation), insulation types that completely fill the CMU cavity and reduce the heat loss through convection include: perlite, vermiculite, sprayed polyurethane, or polycyrene. The last two products will completely fill in all cavities; the former two may settle at the top CMU rows.

• Aside from the energy-cost savings, a masonry wall without air convection in the CMU cavities is less likely to develop moisture condensation problems, as cold air is no longer permitted into the wall. Thus, the life of the wall could be increased.

## Series Matrix: Guide #3

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## Additional Information

**Key Words for Internet Searches**

Thermal bridging, dew point, insulation, airtight construction, moisture condensation

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High Performance Renovation: Windows and Skylights

Philadelphia High-Performance Building Renovation Guidelines

The Role of Windows and Glazing

Of all the systems that compose the shell of a typical municipal building in Philadelphia, windows have the strongest effect - both favorable and unfavorable - on energy use, thermal comfort, and visual comfort. Windows also have a significant impact on the size of the heating and cooling systems. In some buildings, curtain walls bring light into spaces through vision panels, which may be fixed or operable. If operable, they are again called windows. Skylights, clerestories, and roof monitors can be used to introduce light from above (1). In essence, clerestories and roof monitors are windows mounted overhead. All these building systems are referred to as fenestration.

This Guide discusses opportunities to improve the energy efficiency and the indoor environmental quality of buildings through high-performance fenestration. Such fenestration has low-e glass and thermally-broken frames. With some exceptions, it has fairly high visible transmittance but lower acceptance of solar gain, and is airtight and watertight.

Even in situations where high-performance fenestration is unsuitable because of historic considerations, windows or skylights can still be improved in a cost-effective manner. Fairly small upgrades can result in a large decrease in energy use where the starting point is single-pane glass with solid steel frames.

All fenestration systems must bring in light, but ideally should not admit excessive solar heat. They must protect the interior from water penetration and wind. They must be insulating enough to avoid drafts and moisture condensation during winter. Most windows and vision panels offer views, and some window systems are operable for emergency egress and for natural ventilation.

Philadelphia’s climatic characteristics indicate that, in most cases, the fenestration system should be insulating, quite airtight, and with glazing that has fairly high visible light transmittance. Even with these general criteria (discussed in more detail in the "Materials and Systems" section) the best fenestration system for a building, or for a space, may not be ideal for another. Selection varies according to criteria that also include the following:

- The function of a space affects the visible transmittance of the glazing. For instance, consider whether there is a need for moderate light levels (such as 30 footcandles [fc] in office spaces with intensive computer use), or whether the light intensity should be greater.

### Terminology

- **Center-of-glass U-factor:** Measure of insulating value of glazing by itself, not including frames, mullions and spacers. A lower U-factor is more insulating.
- **Clerestory:** Overhead windows.
- **Glass surface number:** Count from outside-in (2). For double-pane glazing the exterior surface of the exterior pane is #1, and the interior surface of the interior pane is #4.
- **IAQ:** Indoor Air Quality
- **NFRC label:** Rating for windows and skylights by the National Fenestration Rating Council (3). The label rates U-factors, SHGC, VT, and air leakage (optional).
- **Roof Monitor:** Device at the top of a roof that provides light, and sometimes ventilation, through vertical glazing.
- **Shading Coefficient (SC):** Measure of heat gain through glazing due to solar radiation. This is the ratio between how much solar heat comes through a given glazing assembly when compared to the solar heat that comes through 1/8-inch, clear, single-pane glass. Lower SC results in lower cooling load. Multiply by 0.86 to obtain approximate value for solar heat gain coefficient.
- **Solar Heat Gain Coefficient (SHGC):** Measure of heat gain through glazing due to solar radiation. This is about 86% of the shading coefficient. A lower SHGC means lesser heat gain.
- **Spectrally selective glazing:** Low-e glazing that allows more visible light through than solar heat (e.g., 70% of visible light but only 43% of solar heat).
- **U-factor for entire window or skylight unit:** Measure of insulating value for the entire fenestration assembly, with glazing, spacers and frame. The U-factor for a fenestration unit is almost always higher (less insulating) than for the glazing.
- **Visible light transmittance (VT):** Fraction of visible light transmitted through glazing.
The Role of Windows and Glazing (cont’d)

(such as 50 to 70 fc in a classroom or library). Related considerations include:

- The relative importance of avoiding glare at all times.
- The relative importance of daylight and views (See Guide #5: Using Natural Light for glazing design issues that pertain to daylighting of buildings.)

- The space use also affects the insulating properties of the fenestration unit (U-factor, airtightness):
  - Determine whether it is important to avoid drafts near windows. Factors include whether the windows border a circulation space or a desk; whether windows are located in a kindergarten or in an office; and whether skylights must be insulated to avoid any downdrafts (e.g., offices), or whether cool air descent is acceptable to some degree (e.g., in lobbies).
  - Orientation of windows and skylights plays a role in the selection of visible transmittance and solar gain characteristics (shading coefficient or solar heat gain coefficient; also desirability of shading devices).
  - For example, north-facing glazing can be more clear than south-facing glazing without incurring high solar gains; but glazing with high visible transmittance might also work well on the south façade if protected by horizontal shading devices.

- Adjacent buildings affect the selection of the glazing:
  - West-facing glazing has to mitigate glare and excessive high solar heat, but not if a nearby tall building keeps the west façade in shadow for most of the critical period of 1 PM to 4 PM in summer.

Timing / Staging

A high-performance fenestration system should be considered in the initial stages of a renovation project. Such a system will reduce heating and cooling loads, which in turn will permit you to downsize the heating and cooling equipment. If the reduction is substantial, the type of HVAC system could change – for instance, baseboard radiation could be eliminated, and all heating could be achieved with forced hot air.

If the walls are renovated and insulated/airtightened at the same time with the fenestration, deeper reductions in HVAC size can accrue. Of course, adding insulation to the roof further improves performance.

Operable windows and the HVAC system should be integrated to save energy. For instance, a contactor mounted on the window sash can signal the VAV box to close if a window opens. Such systems are expensive, but might be attractive if installed in conjunction with a security alert system.

Regardless, operable windows can be provided as an amenity or as a means to cool the building in case the HVAC system fails. In such instances, occupant education on energy use and sustainability becomes very important.

When planning an upgrade of the fenestration system, also consider the lighting system, for two reasons. First, a reduction in solar heat gain through windows could be sufficient to downsize the cooling system, but the chances for this happening are much better, and the savings higher, if fenestration replacement is undertaken in conjunction with a reduction in lighting density. Second, a well-designed fenestration system permits daylight dimming strategies – either then, or at a later date (see Guide #5).

System Integration

Walls and heating system

In a building with large glazed areas, a window upgrade (3) will probably reduce the size of the heating system, but the savings will be more extensive if the walls are high-performance too.

For example, single-pane windows with steel frames could be replaced with double-pane, low-e windows with thermally-broken aluminum frames (4). This will trigger a reduction in boiler capacity, but the size of pipes and pumps might not be affected unless a wall upgrade is also undertaken.

Similarly, building occupants will not feel cold when positioned near a high-performance window, but they might still be uncomfortable at times if the walls are uninsulated. If possible, existing walls should be insulated to code-required levels (See Guide #3). In winter, a person near the perimeter of a building radiates heat toward walls and windows. If these surfaces are cold (as is the case with uninsulated walls or with single-pane windows), the person feels chilled and needs warm room air to be comfortable – often in the 74ºF to 76ºF range. However, with better walls and windows, the indoor air temperature can decrease by about 1.4ºF for every 1ºF rise in the temperature of the wall/window system, without affecting comfort.
The Role of Windows and Glazing (cont'd)

It may be possible to eliminate below-window heating elements such as radiators when using highly insulating fenestration in conjunction with good walls (5, 6). Fig. 5 shows an example with a window that has thermally-broken frames; a masonry wall with rigid insulation on the winter-cold surface of the CMU wythe; and an insulated and caulked joint between wall and window. Removal of below-window baseboards or radiators saves space.

For spaces where people are not sitting right next to windows (e.g., if there is a circulation space along the exterior walls), fenestration to support the elimination of heating elements has glass with U=0.30 or lower and thermally broken frames. Otherwise, the U-factor should be in the 0.20 to 0.25 range, equivalent to low-e glass with one plastic film tensioned in the interpane space, such as Heat Mirror™. Note that for curtain walls, the term “thermally broken” refers to both windows and mullions.

Lighting, plug equipment, and fans
Windows, skylights, clerestories, and roof monitors can be designed to promote better daylighting (see Guide #5: Using Natural Light). Fenestration retrofit offers an opportunity unlikely to be encountered again for decades. Even if daylight dimming is unaffordable at the time of renovation, a fenestration system designed to function well with this technology will keep open the possibility of installing the daylight system in the future.

Glazing and fenestration interact strongly with lighting, plug equipment, and HVAC distribution to affect the size of the cooling system. The cooling load in a building is produced by:

- lighting;
- heat from computers, printers, cooking, and other activities pursued by building occupants (plug equipment);
- ventilation air;
- solar gain through windows;
- heat from fans and pumps;
- heat released by building occupants;
- heat from warm air infiltrating into spaces;
- other, usually less significant factors.

Chillers and air-conditioners are produced in specific sizes; a relatively small reduction in cooling load may not be sufficient to allow for equipment downsizing. Sometimes a building has large glazed areas facing south or west. In such cases the upgrade to glazing with lower solar heat gain coefficient, or the addition of shading devices, may create the opportunity for smaller-size cooling equipment.

Typically, however, the decrease in chiller size, and even more so the decrease in pipe and fan size, is triggered by the combined effect of better windows (lower solar gain) and of low-density lighting. If an assumption can be made that the plug loads will be smaller than before, the downsizing will be even greater (newer computers and monitors release much less heat than models from just five years ago – and the trend continues).

Fans and pumps release heat when they operate. A simple upgrade in design specs from high-efficiency motors to premium-efficiency motors, which the City has instituted, results in a quick payback and contributes to the reduction of the cooling system.

Because of oversizing, fans and pumps can operate at 85% to 95% of capacity even during the hottest day of the year. Variable speed drives (VSD) decrease the annual electricity use, the peak electric demand and the peak cooling load. This can tip the balance and allow for further cooling system size reductions.

Heat recovery for outside air systems
An enthalpy wheel couples the reduction in cooling load from fenestration, and from all other systems mentioned above, with a reduction in the cooling load caused by humid outside air. See Guide #8: Cooling & Ventilation Systems.

Scale of Importance
1. Repair or replace fenestration units that leak water to prevent mold growth and damage to adjacent wall or roof. Whenever possible use high-performance fenestration for replacement.

2. Repair or replace fenestration that creates persistent moisture condensation to avoid mold growth, or resolve the problem using HVAC methods. Repair could consist of installation of outside storm windows, airtight interior storm windows, or another layer of airtight prime windows. The interior storm windows and the prime windows must be airtight because the exterior pane will be even colder than before. If moist air reaches it, more moisture will condense. The same measures apply to skylights, only the glazing is positioned horizontally or at an angle. Storm windows can look unattractive,
The Role of Windows and Glazing (cont’d)

however, a second layer of prime windows is expensive.

HVAC solutions include the following:
- dehumidification of the air in the room;
- blowing air across the surface of the glazing and frames, to remove the condensate;
- exposing the glazing and frame surface to a radiant panel;
- placing a heat source below the fenestration unit (e.g., baseboard or unit heater);
- heating the frame with electric wiring – since most condensation occurs in the vicinity of the frame.

Replacement with high-performance fenestration may be a better solution than repair or HVAC mitigation.

3. Drafty fenestration, and fenestration with single-pane glass and thermally unbroken frames, are the next priorities. Drafty fenestration can be caulked. For single-pane glazing consider the techniques of item 2, above. Replacement with high-performance fenestration units may be a better solution.

4. Double-pane glazing with frames that do not have a thermal break, or that have a poor/compromised thermal break could be candidates for storm window upgrades, or for replacement. Neither method will yield an attractive payback period. The life-cycle cost could be advantageous if other problems are also solved by upgrading or replacing (e.g., reduced maintenance). The upgrade or replacement is often justified by the need to improve comfort in perimeter spaces.

Glazing Materials and Systems

This section presents information useful for specifying and installing windows and skylights; also examine the “Life-Cycle Assessment” section. Costs for materials and systems, and for their installation, vary according to type (e.g., low-e hard-coat vs. low-e soft-coat), size, special considerations (e.g., historic, security), etc. Check with local contractors to obtain reliable cost estimates.

Use Thermally Insulating Glass ($$-$$$)
The insulating value of glazing depends on:
- number of panes;
- thickness of interpane space;
- whether one or more of these panes have a low-emittance (low-e) coating, and the quality of that coating;
- whether the interpane space is filled with air, argon, or krypton;
- other marginal influences. For example, ¼-inch glass is slightly more insulating than ½-inch.

Tints and reflective coatings -- the type that give a mirror appearance to the glass -- have practically no effect on glass R-value.

- Number of panes. The insulating value of glazing increases with the number of panes. Consider the R-values for ¼-inch glass without low-e coatings. The air space between glass panes is ½-inch thick, air-filled:
Glazing Materials and Systems (cont’d)

- single-pane R=1 (U=1.0) in old windows;
- double pane R=2 (U=0.48) are most common;
- triple-pane R=3.2 (U=0.31) are uncommon, but sometimes this approach/strategy costs less than double-pane low-e glazing, and insulates just about as well.

- Thickness of space between panes
  A vertical air layer has its highest insulating value between ½-inch and 1-inch thickness. This value drops quickly below ½-inch and very slowly above 1-inch. For this reason the most economically effective air layer is ½-inch thick (U=0.48 for double-pane glazing, air-filled). The heat loss increases by 15% (U=0.55) if the air layer is only ¼-inch thick.

- Low-e coatings significantly increase the insulating value of glazings. There are two types of low-e coatings: hard-coat (pyrolitic) and soft-coat (sputtered). A typical double-pane, ¼-inch-thick glass with air between panes with hard-coat low-e has U = about 0.39-0.36 (R=2.6 to 2.8); Soft-coat low-e yields U = about 0.31-0.29 (R=3.2 to 3.5).

Even though more expensive, the soft-coat low-e coating offers about 15% to 25% higher insulating value than the hard-coat option, and yields a better return on investment. For double-pane glazing, soft-coat low-e brings a 35% to 40% higher insulating value than the hard-coat option; it is recommended for all replacement projects (see also Life-Cycle Assessment section).

Low-e glass is marginally more insulating if the coating is deposited on surface #3 instead of surface #2 (see also fig 2 on first page of this Guide) – but then it is marginally less effective in reducing solar gain in summer. If low-e coatings are deposited on both glass surfaces, the insulating value of the glazing assembly increases measurably.

- Argon and krypton are inert gases (gases that do not interact chemically with other substances) used to replace air in the interpane space (7). For double-pane low-e glass with U=0.29, argon fill can increase the insulating value by 10-15%; a krypton fill improves the U-factor by 16-21%.

Argon fill can come at no extra cost (some manufacturers only offer windows that are low-e, argon-filled) or up to about $1/sq ft. Krypton costs about twice as much. Theoretically the gas should not escape to the atmosphere at a rate higher than 0.25% per year, but there are no long-term records. For this reason, it is prudent to specify gas-filled glazing when the payback is less than 10 years. The heating system should not be downsized because of the higher insulating value conferred by these gases.

Argon and krypton give greater advantage when the interpane space must be narrower than ½-inch – a situation encountered in glass replacement of historic windows, where the frame width cannot be altered. For a ¼-inch interpane space the improvement in U-factor of low-e glazing is about 20% for argon and 40% for krypton.

- Highly insulating glazing can be obtained by using multiple panes with low-e coatings, and perhaps gas fill (7). Some low-e glazings have one or two plastic films tensioned in the space between the exterior and interior glass panes (8). These tensioned films have low-e coatings.

One film stretched in-between creates two air spaces – like triple-pane glass. Two films create three air spaces – similar to quadruple-pane glass. The insulating value of these glazings is very high. Low-e glazing with one film can have U-factors in the range of 0.24 to 0.19 (R=about 4 to about 5.3). Two films can reduce the U-factor to 0.13 (R=7.6). At this point the glass is as insulating as a steel stud wall with R-11 fiberglass batts.

Use Insulating Frames ($$–$$$)

Heat flows like water. More water flows through a large opening; more heat flows through an area with high U-factor. If well-insulated glazing is placed in a poor frame, a disproportionate amount of heat flows through the frame, short-circuiting the glazing close to the edges. Only the glazing farther away from the frames counts in terms of its insulating effect. The U-factors for a typical-size window with double-pane, low-e glazing (U glazing=0.29) are listed below, according to the frame material:

- solid steel U=0.70 (R=1.4);
- thermally unbroken aluminum U=0.67 (R=1.5);
- thermally-broken aluminum U=0.47 (R=2.1);
- wood/vinyl U=0.39 (R=2.6);
- insulated vinyl U=0.33 (R=3.0)

It is possible to improve the performance of historical, steel-frame windows, even though steel has a strong, unfavorable effect on the insulating value of the glazed unit:

1. Insulating spacers – like triple-pane glass. Two films create three air spaces – similar to quadruple-pane glass. The insulating value of these glazings is very high. Low-e glazing with one film can have U-factors in the range of 0.24 to 0.19 (R=about 4 to about 5.3). Two films can reduce the U-factor to 0.13 (R=7.6). At this point the glass is as insulating as a steel stud wall with R-11 fiberglass batts.

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Glazing Materials and Systems (cont’d)

- A thermally broken aluminum frame can be provided as replacement – where it is not important to preserve the original frame thickness.
- A thermally broken steel frame can be custom-ordered as replacement. The new frame will have the same height, but will be wider. The thermal break is not very good, but still constitutes an improvement.

The most thermally insulated frame produced at the time of this writing has the same U-factor as a glass with two plastic films stretched in the space between the two glass panes. The U-factor is 0.13 (R=7.6).

Use Insulating Spacers ($–$$)

Even if both glass and frame are insulating, heat can still seep through a third element: the spacers that keep apart the two (or three) panes of glass. Insulating spacers (Fig. 9 on page 5) can improve the U-factor of a typical window or skylight by 3% to 5%. They are composed of silicone foam, fiberglass, or EPDM reinforced butyl, among other materials.

Use Vision Glazing with Low Heat Gain ($$–$$)$

Glazing lets through a large spectrum of solar radiation – the portion of the spectrum that is visible, as well as a large portion that we only perceive as heat (the visible portion eventually becomes heat too). Since most air-conditioned buildings cost more to cool in summer than heat in winter, it is desirable to reduce the amount of solar gain through windows (heat gain is not a concern for north-facing windows or for windows in shade), but in general it is also desirable to retain clear views to outside. For most glazing types, however, a lower solar heat gain is associated with a lower visible transmittance. The exception is spectrally selective low-e glazing.

The listing to the left (10) shows how the spectrally selective glazing reduces heat gain (and therefore cooling energy use) without significantly diminishing the perception of the outside. A higher coolness ratio means that the glass allows better vision with lower heat gain.

Glazings with low solar heat gain coefficient (SHGC) are important for south, east and west orientations. In some buildings, glazings with higher SHGC are used exclusively for the north façade to reduce first cost and increase visible transmittance without an increase in energy use. Because it is difficult to visually differentiate between different glass types, care must be taken during construction and replacement to ensure that the right glazing is installed at each orientation. This is of particular concern when different glazing types are selected to look similar, yet will be positioned on different facades. Light and reflections will cause even the same glazing to look different when positioned at different orientations. See Guide #5: Natural Light for further discussion.

Install Airtight Windows, Skylights, and Curtain Walls ($$$–$$$$)

Windows should be airtight. Fixed windows are most airtight, followed by operable windows with positive closure: casement, awning and hopper (11, 12). All windows can be specified and purchased with tighter or looser characteristics. The price differential between an airtight and a loose window is relatively small, and the advantages for air tightness are considerable.

Loose windows create drafts and promote air infiltration. Air infiltration not only wastes energy; it also pulls pollutants -- and in case of fire, smoke -- from lower floors to higher floors. Finally, in mechanically ventilated buildings, air leaking around window frames is less clean than the one introduced through the filtering system.

Some believe that a leaky building shell is needed to maintain a pressure differential between inside and outside. The reasoning is as follows: If more outside air is supplied than exhausted (to pressurize the building) where will that air go in an airtight building? Response: a small amount of air leaks in and out the tightest buildings. In these buildings, pressurization is achieved with less excess outside air. A variable speed drive on the fan (even on a constant volume fan), and a modulating outside air damper can be used to adjust the amount of outside air for the exact pressurization desired.

Use Environmental Materials ($$–$$$)

Most commercial fenestration systems on the market consist of aluminum, steel, wood and/or plastic frames, plastic thermal breaks, and glass.

- Aluminum has a substantially higher embodied energy (energy required to manufacturer the material from ore) than other materials used in building, even steel, but the industry incorporates a high percentage of recycled content (25% to 75% range). The material is light-weight, durable, and virtually maintenance free.
- Steel - all steel products have a substantial recy-
Glazing Materials and Systems (cont’d)

cled content (minimum 25%).

- **Wood** - a growing number of window manufacturers offer products where wood originates from sustainably harvested forests, as certified by the Forest Stewardship Council (FSC) and/or SmartWood™.

Wood is susceptible to rot and must therefore be preserved, and then stained, painted, or covered. Preservative treatments typically include at least one toxic chemical (to keep insects away), as do mildew-resistant paints and stains. Many wood window manufacturers offer plastic and metal claddings to reduce these maintenance requirements. Fire codes restrict the commercial applications of wood windows.

- **Plastic** is light and low-maintenance. It does not have recycled content in window applications, but this situation may change in the future. Commercial buildings rarely use plastic window frames because the frames shrink and expand substantially with temperature fluctuations; they also may not meet fire codes. However, plastic is used as a thermal break for metal windows (typically aluminum and sometimes steel.)

In general, fiberglass frames are more dimensionally-stable than vinyl frames. Fiberglass is also associated with fewer environmental problems.

- **Sealants and caulks** - The U.S. Green Building Council’s LEED rating system, and other equivalent green building guidelines, promote VOC limit of 250 g/l for interior architectural sealants. Most major manufacturers have product lines that comply with this VOC requirement.

### Reduce Construction Waste ($$)

All frame materials, with the possible exception of plastic, are recyclable, as is glass. Most jurisdictions will have private or public recycling haulers and processors for these materials.

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**Benefits**

- **Comfort**
  Windows are typically the least insulating elements in a room, so an improvement in their U-factor significantly increases the thermal comfort. See also the "System Integration" section.

- **Energy Savings**
  Insulating, airtight, spectrally selective windows and skylights result in significant energy savings.

- **Reduced Emissions**
  Lower energy use results in fewer emissions of CO₂, NOₓ, and SOₓ.

- **Resource Conservation**
  Use of materials with recycled content, and diversion of demolition matter from the waste stream, decrease the pressure on natural resources. The latter action also decreases landfill use.

- **Noise**
  Thermally improved windows with lower U-factors (higher R-values) can also improve acoustical performance. Windows with glazing layers of varying massiveness (i.e., some glass, some stretched plastic) may offer unique acoustical advantages for noise of certain wavelengths. Also, airtight windows reduce noise transmission.

- **Indoor Air Quality**
  Windows and skylights with moisture condensation can create mold growth on their own surfaces, as well as the adjacent wall and ceiling (13). A thermal upgrade eliminates such problems.

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2. For example, the VOC limits are required by California Regulation 8 "Organic Compounds," and by Rule 51 “Adhesive and Sealant Products VOC limits for the Bay Area Air Quality Management District.”

13 Mold growth
Life-Cycle Assessment

Some windows are replaced after 20 to 25 years, but many remain in service for 50 years or longer. For this reason, simple payback calculations seem quite inadequate. Even the life-cycle cost could be easily extended from the typical 20-year span to a more realistic 50-year period, to give a better picture of the true cost of installing and owning fenestration systems.

Account for the effect of better windows and better skylights on the size of the heating and cooling systems when calculating the first cost of renovation. Window replacement is rarely justified only by energy savings. Rather, it is triggered by a need to improve comfort, stop the deterioration of the wall, enhance security. The cost for higher performance fenestration is offset in part by smaller boilers and furnaces, smaller chillers and rooftop packages, smaller ducts and pipes, smaller pumps and fans. If the walls are also upgraded at the same time, it might be possible to achieve greater savings by eliminating portions of the heating system (e.g., the baseboard radiation).

Energy savings always justify upgrading the glazing to soft-coat, double-pane, and low-e. Most often spectrally selective double-pane, low-e has a good return on investment. Argon and krypton gas may or may not be cost-effective in Philadelphia. Glazings with one or two plastic films stretched in the interpane space (like Heat Mirror) tend to be cost-effective only if they induce savings in the first cost for HVAC.

Account for the effect of better glazings on daylighting systems. The energy savings produced by these systems are greatly enhanced by spectrally-selective glass.

Maintenance and repair have a strong effect on the life-cycle cost of windows and skylights. Glass is a durable material that only needs replacement when broken. Life of the frames depends upon attentiveness to maintenance (i.e., painting). Framing materials typically have a useful life of 20 to 50 years depending upon type of deterioration such as rot (wood windows), and corrosion (metal windows).

There is no indication yet that low-e coatings deteriorate over time.

Series Matrix: Guide #4

Guide
- 1. Site Issues and Improvements
✓ 2. Roof Repairs and Replacements
✓✓ 3. Upgrading Exterior Walls
- 4. Windows and Skylights
✓✓ 5. Using Natural Light
✓ 6. Electric Lighting Systems & Controls
✓✓ 7. Heating System Upgrades
✓ 8. Cooling and Ventilation Systems
✓ 9. Controls and Building Automation
- 10. Water Management
✓ 11. Environmentally Preferable Materials
✓ 12. Emerging Technologies
✓✓ High Relevance
✓ Moderate Relevance

Additional Information

Key Words for Internet Searches
Dew point, insulation, low-e, window frame, argon, krypton, insulating glazing, insulating spacer, thermal break
The Role of Daylighting

The selection of fenestration systems and of daylighting strategies is made simultaneously (refer to Guide #4: Windows and Glazing).

A space requires natural light according to its function. Museums must carefully control natural light levels to avoid damaging the artifacts – a highly specialized function that is not discussed in this guide. Storage areas, restrooms, and equipment rooms are seldomly daylit. Conversely, natural light is very useful in offices, conference rooms, lobbies, and public corridors. In renovation, the designer should endeavor to coordinate the location of a function based upon the availability of natural light.

Daylighting has several functions:
• Daylight informs about outside conditions and provides a sense of well being. People feel changes in weather using as clues such as the color and intensity of natural light, even if this light originates from a hidden source, as might be the case with lower level offices that have windows toward a skylit atrium. A direct view of the sky is even better. In office buildings, such views can be achieved with transoms located at the top of the wall between interior and exterior offices (1). However, a window view is by far most valued and should be provided whenever possible to enhance occupant well being and productivity. Always consider operable windows – they add valued personal control over the work environment, and could save energy if used properly – see also Guide #9, "HVAC Controls and Building Automation."

In some European countries, a workstation cannot be located more than 30 feet from the outside wall. American office buildings built after World War II tend to have wide footprints with much workspace far from windows (up to 60 feet is not uncommon), while earlier office buildings that originally relied on natural ventilation kept workspaces near windows. Renovating requires a different daylighting strategy for each type.

• Daylight improves productivity. Stores sell more merchandise in daylit areas (2). There are strong indications that absenteeism decreases and output is better for offices and schools that benefit from natural light. To create such a positive environment, keep in mind that a well-daylit space is superior to one that has only on occasion sufficient daylight. Areas located beyond 15 feet from regular-sized windows do not get good daylight for much of the year. A California study correlates better student performance with classrooms where windows are supplemented with light shelves (to throw light deeper into a space) and skylights.

• Daylighting makes a powerful architectural statement. Adding an atrium or fully glazing a wall makes a strong architectural statement. Direct sun from such large glazed areas can be undesirable or can enhance the

Terminology
Frit: Ceramic deposit on glass, usually as dots or strips. When deposited on vision glass, the frit can be light-colored or dark-colored. Light frit can create glare when illuminated by the sun, but at night it makes the glass appear solid. Dark frit creates no glare, but at night cannot be seen – the windows seem black to a person looking out. Frit deposited in a denser pattern reduces the visible transmittance of the glass to a greater extent.

Footcandle: The quantity of light falling on 1 square foot area that is one foot away from a light source with the power of one candle.
Illuminance: Measure of light falling on a surface. Measured in footcandles (fc).
Soffit: Underside of an eave or overhang
Transom: Window above an interior door or at the top of an interior wall
Solar Heat Gain Coefficient (SHGC): Measure of heat gain through glazing due to solar radiation. This is about 86% of the shading coefficient. A lower SHGC means lesser heat gain.
The Role of Daylighting (cont’d)

Daylighting and its control should be considered in the initial stages of a renovation project, for the following reasons:

- **Layout.** Place workers near outside walls or interior light courts. Conference rooms should benefit from daylight too, if at all possible. Relegate storage, restrooms, and mechanical rooms to the core.

- **Configuration of windows and skylights.** A space deeper than 15 feet is best served by tall windows (possibly with light shelves), or by adding overhead lighting, such as clerestories, roof monitors, or skylights. Windows facing south, east, or west are best protected from glare and from excessive heat by exterior shading devices. These architectural decisions are difficult to make late in the design.

Daylighting saves energy if electric lighting is turned off or dimmed (5). Some occupants turn off their lamps when it is bright outside, but in most cases the electric lighting is left on. Automated controls reap electricity savings. Even if these controls are unaffordable at the time of renovation, lay out the lighting fixtures on electric circuits that are parallel to the perimeter. This way, at a later date, daylight controls can be economically retrofitted for the fixture row closest to the windows, or even for the two fixture rows closest to the windows.

**HV/AC sizing.** Typical HVAC sizing procedures assume that on the hottest, sunniest day of the summer, when all shades are pulled up, a room will have all electric lights on. Reasons usually given for ignoring the effect of daylight dimming on HVAC size include:

- The dimming system could be inoperable at the time of cooling peak. This is a valid concern for areas where peak summer sun only allows for partial dimming of the lamps. In a well-designed space, however, natural light completely eliminates the need for electric lighting during peak cooling periods.

- The dimming system might not function at the time of cooling peak. Even if the dimming system does not function, the lights can simply be turned off manually. This is especially the case for corridors and sometimes for lobbies that have one or more walls fully glazed. In these spaces natural light is very intense for most of the year – not only during peak cooling. There is no functional reason why the electric lighting cannot be automatically turned off, based on the light reading of a sensor.

Note that in spaces bathed with natural light, dimming does not always save additional energy when compared with on/off controls. During cloudy periods dimming reduces electricity use compared with an automatic on/off control, but at other times a dimmed lamp still uses 10 to 20% electricity, compared with no electricity use of the on/off control. Energy modeling can indicate which control strategy is best.

**System Integration.** Windows, skylights, clerestories, and roof monitors can be designed to promote better daylighting. Natural light should be sufficient during overcast days, but should not create glare during sunny days. Glazed areas should not be a source of excessive heat gain in summer, or of intense heat loss and draft in winter. These requirements can only be met if the fenestration is specifically designed for proper daylighting.

Daylighting reduces the need for electric lighting if it is properly controlled. Light can enter through windows, skylights, and glazed roofs, roof monitors, or (in low-rise non-fireproof buildings) through light tubes (3). Each source provides a different kind of light to a different part of the building, and each requires different control strategies.

**Timing/Staging.**

Perform a daylighting assessment. Before renovation planning begins, it is useful to make a walking tour of the building on an overcast day, preferably with a light meter in hand, to assess the opportunities for natural light (4). This survey will assess the effect of surrounding buildings and vegetation, and point to the desirability of enlarging existing glazing or re-opening closed overhead glazing.

Before renovation, lay out the lighting fixtures on electric circuits that are parallel to the perimeter. This way, at a later date, daylight controls can be economically retrofitted for the fixture row closest to the windows, or even for the two fixture rows closest to the windows.

**Fenestration and daylighting.** Windows, skylights, clerestories, and roof monitors can be designed to promote better daylighting. Natural light should be sufficient during overcast days, but should not create glare during sunny days. Glazed areas should not be a source of excessive heat gain in summer, or of intense heat loss and draft in winter. These requirements can only be met if the fenestration is specifically designed for proper daylighting.
The Role of Daylighting (cont'd)

capacity based on the need to maintain sufficient airflow; this could mean lost opportunities to save energy in such daylit, low-cooling-load spaces.

Fan-powered VAV boxes throttle the primary airflow down to the minimum required for proper ventilation (sometimes 10% of total airflow). In addition, fan-powered VAV boxes can reclaim heat from core areas for use in perimeter areas. Both approaches are usually cost-effective.

Scale of Importance

1. Enhance the effectiveness of existing daylighting sources. Fenestration retrofit offers an opportunity unlikely to occur again for decades. Window and overhead glazing should be selected to both reduce energy use (see Guide #4) and enhance natural lighting.

2. Restore daylighting sources that have been closed (6). Often, tall windows have been partly closed to reduce energy costs. Overhead glazing has been covered for more varied reasons: to save energy (as in the 1970s and early 80s), to avoid repairing leaky skylights and monitors, or merely to eliminate the need to clean hard-to-reach surfaces. In some instances, overhead glass was closed during World War II blackouts and never re-opened. It is usually beneficial to restore these apertures, using the more efficient, modern glazing technology and modern daylight control. The value of the electric lighting displaced can more than compensate for the additional solar gain in summer and heat loss in winter.

3. Associate the functional requirements of spaces with the available sources of daylight. To the extent possible, given the many constraints on the planning of a building, consider relating the various spaces to the resources available. For example, if west-facing glazing is unavoidable, place spaces on the west facade that are less sensitive to direct sunlight, such as corridors and eating areas.

4. Add new natural lighting sources. New windows and skylights, when coupled with automatic controls, save energy. The energy savings alone cannot justify the new apertures. The monetary value lies in increased productivity. In retail or commercial spaces, additional value lies in measures such as increased sales or higher lease prices.

Daylighting Issues

A successful daylight design takes into account the desire to admit as much natural light as possible, for the longest time possible; the need to reduce (or at least not to increase) energy costs; and the imperative that natural light not impede work activities. With very rare exceptions, this does not mean that natural light must be controlled perfectly, 100% of the time. A daylighting system must be controllable for most of the time, and certainly during critical periods, but not at all times. Some museums require perfect light control, but the associated high cost is unjustifiable for other buildings. There are functions that need more careful light control than others – e.g., laboratories vs. classrooms.

- Daylight reaching a space is highly variable. Direct sun is too bright for most work environments, while cloudy skies emit even, diffuse light. But a white, cloudy winter sky can still be uncomfortably luminous. North-facing windows receive direct sun rarely and briefly, but the other cardinal orientations have extended periods when the sun is low and can reach deep into the space, with potential for significant visual discomfort (7). Thus, control is key to the efficient use of natural light.

- Reducing Contrast. Sunlit glass could easily be more than 100 times as bright as the surrounding wall or nearby ceiling, creating visual discomfort (a factor of 100 is the rule-of-thumb limit to acceptable visual contrast). Isolated (“punched”) windows separated by areas of wall create contrast between wall and glazing. Objectionable contrast can be created by exterior surfaces that are seen against a clear sky, or against a bright, overcast winter sky – such as the underside of an overhang that is painted dark. There are several ways to reduce contrast:

  - Create gradual transition between glazed and opaque areas. In buildings with thick walls, bevel the window jambs, if possible, to create partially-lit transitions between the window and the unlit wall.
  - Create nearly continuous glazing bands. The ambient light level in the space rises and
Daylight Issues (cont’d)

the side-by-side contrast between wall and window is reduced. In this context, “horizontally continuous” means that the
mullions between windows are less than about 20% the width of the window.

- Increase the brightness of the wall, ceiling, or soffit
  by using light-colored finishes. Place light shelves on the window (if the window and
  ceiling height permit) to reflect some of the light onto the ceiling and reduce the
  window/ceiling contrast (δ). The underside of the light shelves should be
  light in color.

- Place electric lighting close to perimeter, including
  perhaps wall washers.

- Reduce direct sunlight using exterior shading
devices.

- Eliminate or reduce both direct and indirect
  sunlight with interior curtains and blinds.

- Use glass with a lower visible transmittance, or
  with a dark ceramic frit.

- Direct glare. Sun low above the horizon causes
glare if it is in direct line of sight. This condition
occurs all year on east- and west-facing walls in
the morning and evening respectively, and
during winter on south-facing walls during the
middle of the day. Near-north-facing glazing
typically does not need glare control because
sun strikes the facade at raking angles at times
that are mostly outside working hours. (“Near-
north-facing” means from 45° east of to about 30° west
to true north).

- Reflected light. In urban areas adjacent glazed
buildings can create serious glare problems at
unexpected times. For example, peak glare
conditions might occur in the morning on west-
starting windows if there is a highly reflective
curtain wall to the west of these windows.
North-facing windows can become a glare
problem if they face a building with highly
reflective façade, and if that building is across a
very narrow street. (The building must be
closely located to create glare by reflection,
because the south sun is high.)

Sometimes glare is caused by reflection off
bright horizontal surfaces, such as a lake or a
white roof (see also Guide #1).

There are three typical solutions to direct glare:

- Exterior sun control devices (10),

- Interior shading devices, including light shelves
  and interior movable shades, and

- Glazing that has a very low visible transmittance –
  below 10%.

- Thermal Effect v. Glare. Exterior sun control
devices are typically designed to control the thermal effect
of sunlight. For example, horizontal louvers at
near-south-facing glazing can block direct sun from entering between (for example) March 21st
and September 21st, a period where the weather
is generally warm, while allowing direct sun the
rest of the time, when it is generally cooler. The
glazing is then chosen with a relatively high
SHGC (and therefore a high visible
transmittance, or VT) so that it provides useful
solar heating during cold weather.

Such an approach fails in situations where occasional
glare is not tolerable. For example, direct sun
entering at a low angle in December can be too
bright for a workstation, requiring interior sun-
control devices (movable blinds, for example) to
block the sun. Thus, external sun control
devices are typically designed to control the thermal effect
implies (for more glare-sensitive space
functions) the use of a low VT window glazing,
or the use of interior blinds. Otherwise the
exterior shading device should be sized to
reduce (or eliminate) glare year-round.

On east- or west-facing walls, horizontal shading
devices have limited effectiveness, because the
light is often cast at low sun angles. Vertical fins
offer very good protection from glare and summer heat
gain, but they block views. Any exterior sun
device makes window washing more difficult.

- Glare based on directional orientation

- East Glare—Most east glare occurs in winter,
between 8am and 10am when the sun is low.
Because weather in Philadelphia is frequently
cloudy, the occasional winter sunshine can be
pleasurable, so most workers may be willing
accept temporary glare conditions during a
brief, early morning period. In addition, taller
adjacent buildings may block this early sun.

In summer some of the east glare can be reduced with
relatively narrow horizontal overhangs, because by
10am the sun is already quite high on the sky.
These partial solutions can be successful if
combined with a plan layout that assigns the
first 3 to 6 feet of perimeter to circulation or
activities that do not require computer use
during early morning.

The only other alternatives are to provide interior
movable shading devices, or glass that has very low
visible transmittance. However, low visible
transmittance glass will reduce daylight levels
even when natural light is desirable.
Daylighting Issues (cont’d)

- West Glare—Most west glare in winter occurs late in the day, when it can be treated similarly to the east glare. However, west glare is more problematic in summer because it coincides with peak cooling. If vertical fins are undesirable, only movable interior devices, or glass with very low visible transmittance, can eliminate acute visual discomfort.

Interior shading devices are necessary to control glare on the west façade, and sometimes on east and south, in the absence of exterior shading devices.

- Measures to address glare
  - Light shelves are horizontal strips, usually 1 to 2 feet wide, that are located above vision glazing at a height of about 7.5 to 10 feet. These devices can be exterior, interior, or combined (part inside and part outside). An exterior light shelf collects and bounces off the light into areas farther away from the perimeter (typically beyond 15 feet), increasing the light levels in these spaces. Interior light shelves do not have a significant effect on areas removed from the perimeter, since these light shelves do not capture additional light. They only redirect existing light, and in the process of redirection they absorb some of the light, so the total effect on remote spaces is minor.
  - All light shelves create a more uniform light distribution, reduce the areas with high visual contrast, and protect areas located immediately below the light shelves from direct solar radiation. Even a narrow shelf captures most of the direct solar gain in summer because the sun is relatively high in the sky for most of the day.
  - Light shelves are effective for south-facing glass. East and west facades also benefit from these devices, because in summer they block most direct sun between 11 am (east) and 1 pm (west), and they help somewhat at earlier hours (east) or later hours (west). If early morning glare is not a major issue, a combination of narrow overhangs and light shelves can be satisfactory for an east façade (e.g., for a branch library that opens to the public at 10 am). A west façade will necessitate movable shading devices.
  - Window blinds (11) solve any glare problem but are a serious maintenance problem. In addition, some blinds are closed (fully or partially) during sunny periods and never pulled up again.

Blinds can be protected from physical damage by placing them between panes of glass. As the blinds must be accessible for maintenance and cleaning, the glass needs to be double-glazed outside the blinds, with an added sheet inside. If the blinds are placed between two single-pane windows (an existing exterior one and a retrofit interior one), the interior window must be airtight to prevent moisture from reaching and condensing on the outer pane. Windows with internal blinds are commonly used in Europe. Like any mechanical solution, regular maintenance is essential.

- Glazings that are diffuse and have average visible transmittance (e.g., in the 30% range) cause more glare than non-diffusing types. Glazings with very low transmittance, include highly reflective glass (sometimes with gold appearance), heavily fritted glass, glass blocks, glass channels, and plastic assemblies. None of these glazing types, however, offer clear views.

Strong diffuse light causes extreme visual discomfort (for example, direct sun against white translucent glass). For this reason, a heavily fritted glass that is selected to eliminate glare on an east or west façade must have dark frit; white frit will glow in direct sun.

- Veiling glare. Computer work requires a fairly low illuminance, in the 25 to 40 fc range, and uniform light on screen. Direct sun always creates glare, but sometimes light reflected by ceiling, walls, or furniture also interferes with the legibility of the information presented on-screen. This veiling glare can be caused by strong sources of natural and electric light (12).

Control techniques include:
  - Using indirect overhead lighting, or shielding downlights.
  - Reducing the intensity of natural light at the time when it causes veiling glare, by using exterior shading devices, interior shading devices, or glazing with lower visible transmittance (see paragraph above).
  - Changing the geometry of ceiling or light shelves, to modify the light distribution.
  - Using matte finishes on surfaces that reflect light onto computer screens.
  - Re-arranging the workstations, to turn the computer screen away from the light. The user can tolerate increased contrast when raising the eyes off the screen, as opposed to the contrast present on the screen itself. But the contrast between screen and the light source in view should not surpass a ratio of 1:100.
Daylighting Strategies

- Using anti-glare, flat-screen monitors.

Daylight can be introduced into spaces using many strategies, some of which are noted below.

Open the Building Perimeter to General Office Space ($) ($) (13)
If the tenant organization is amenable to the idea, the open office space can extend to the outside wall, providing access to natural lighting and views for the maximum number of workers. Private offices in this scheme are either toward the interior, or are located in "peninsulas" of back-to-back offices that extend from the center of the building to the perimeter wall, interrupting the general office space (which typically would be subdivided by half-high partitions). The private offices have fully or partially glazed walls to the general office space, with curtains or blinds where necessary for privacy. Conference rooms also can be glazed toward the general office space and located away from the perimeter.

Transfer Light Through Perimeter Spaces ($-$) ($-$)
If the perimeter is reserved for private offices, light can be transferred to the interior spaces by partially or fully glazing the inside walls of the perimeter spaces. If ceilings are high, transoms (14) can transmit light along the ceiling, perhaps from high windows above light shelves on the perimeter. For privacy, the lower glazing toward the interior can be translucent (transmitting light but not view), perhaps of glazed block, or can be curtained. Upper glazing is more effective if left clear.

Reopen Closed-off Overhead Glazing ($-$-$) ($-$-$) (15)
Many older buildings had one or more light courts in the center of a large block, to keep spaces close to an exterior wall. At some level, typically above the first or second floor, the court would be glazed over. In many instances, this glazing has been covered. Restoring the glazed roof can open up interior spaces on the lower floors to natural light, enhancing the architectural character and allowing reduction in lighting energy. Reglazing an existing mullion structure is sometimes possible, but more typically an entirely new glazing and mullion system is installed. The new system can incorporate thermally broken mullions to eliminate the thermal short-circuits that typically occur in older overhead glazing structures.

Some low-rise buildings likewise have closed-off or roofed-over skylights, clerestories, and roof monitors that can be replaced with new glazing systems.

Enclose an Open Light Court ($$$-$$$$$) (15)
It is possible to glaze a light court at any level, creating an atrium. This strategy adds new usable space at the ground floor (and possibly at a mezzanine) that is naturally lit. The space could then function as an eating area or lobby, perhaps with interior plants. If the atrium covers the windows of usable spaces above, it would need a fire exhaust system, which adds to the cost.

Create Light Shelves for High Spaces ($-$)$-$)
Older buildings frequently have high floor-to-floor heights. When renovating for modern uses, it is not uncommon to block off the upper part of high windows and drop a ceiling to a normal 9- or 10-foot height. Instead, it is possible to install a light shelf at 8 to 9 feet above the floor, and to provide glazing above the shelf, leaving the ceiling as high as possible. By glazing the upper part of the walls between the perimeter and interior spaces, natural light can bounce off the light shelf into the interior spaces. Light shelves work best on near-south-facing facades.

Add Skylights, Clerestories, or Roof Monitors ($$$-$$$$$)
Interior areas at the top story can be naturally lit by glazed openings in the roof. These should be located carefully, taking account of the fact that today’s space planning layout may change in future years. Consider locating eating areas at the top floor, as they nearly always benefit from generous overhead glazing. Any sort of lobby, such as that associated with a conference facility, is also a good candidate for overhead glazing.

Roof monitors and clerestories are like high-placed windows. They have vertical glazing, eliminating the maintenance problems associated with near-horizontal glazing. They are ideally oriented north, allowing the use of clear glass with no sun control measures, or oriented south, since protection from direct sun is relatively easy for that cardinal direction.

The best SHGC varies by orientation, with lower values -- in the range of 0.37 and below (and therefore lower heat gain) for south and west, and higher values for north. East-facing vertical glass could have a higher SHGC if the space below is heating-dominated. Skylights should typically have...
Daylighting Strategies (cont’d)
a low SHGC, on the order of 0.37 and lower, to
avoid using more energy for cooling than is saved
in lighting (see Guide #4).

Consider using blinds or baffles on overhead glass
to reduce the chance for glare.

Provide Different Glazing Types According to
Orientation ($) Because north-facing glazing typically does not
need glare protection, it is possible to specify a
different, more clear glass for north facades than
for the other facades. If the south glazing is
shielded with horizontal sunshades, it may make
sense to make the north and south glazing the
same, with a high VT and higher SHGC. The east
and west glazing would both have a lower SHGC
and, possibly, a lower VT.

Fig. 16 shows an example of a low-e, spectrally-
selective glass, with a solar heat gain coefficient
that is much lower than the visible transmittance.
This type of glass would be most useful on
unshaded south, east and west facades, but is not
necessary for the north facade. North-facing glass
could have a SHGC approaching 85% of the
visible transmittance value without a significant
effect on energy cost. The low-e glass with high
SHGC is less expensive than spectrally-selective
glass.

Benefits

• Comfort
  Daylight, especially if coupled with a view, is
  highly prized and provides a feeling of well-
  being that translates into higher productivity
  and higher sales. Glare control is important
to a successful daylight design.

• Energy Savings
  Daylight in public spaces can substitute for
electric lighting, reducing peak electrical
demand. Automatic controls (daylight
dimming, on/off daylight control) are
required for reliable savings.

• Reduced Emissions
  Reducing electricity use (both for lighting
  and for cooling) decreases off-site emissions,
including CO₂, SO₂, and NOₓ from power
  plant operation.

• Resource Conservation
  Reducing the daily operating time of electric
lighting increases the life of lamps and delays
their disposal.
Life-Cycle Assessment

Daylighting is a significant factor in the cost-benefit analysis of fenestration, lighting, and to some extent, HVAC selection. Energy and lighting computer analyses can be used to ensure that the selection of new glazing and sun-control devices is optimized for daylighting as well as thermal performance. DOE-2 is a powerful, public-domain computer program that is appropriate for quantifying the effect of daylighting on energy cost. RADIANCE is its counterpart for assessing the visual effect of daylight (footcandles, brightness, potential for glare). Note: EnergyPlus, under development at the time of this publication, is expected to replace DOE-2 in the near future as the energy modeling tool of choice.

Daylighting brings many psychological and physiological benefits that can translate into greater productivity, increased sales, or higher rent value. However, daylighting cannot always be justified based on energy savings alone.

The selection of appropriate glass, and the use of daylight control systems (daylight dimming and on/off daylight controls) can yield an attractive payback, often in the 3- to 6-year range. Any incentives from electric utility companies make this payback even more attractive. Energy savings, on a life-cycle cost basis, can sometimes justify light shelves, if daylight dimming is implemented deep into the building (e.g., 25 to 30 feet away from perimeter). The same applies to transoms and glazed interior walls at perimeter private offices.

Exterior shading devices are primarily installed to enhance to the quality and functionality of the space. Energy savings related to exterior shading are insufficient to justify their use, unless the HVAC systems is downsized because of these permanent shading devices.

Within a 20-year life-cycle horizon it is unlikely that roof monitors, clerestories, skylights, or glazed-over atriums can be justified through energy savings alone. Their most important contribution is in enhancing quality-of-life and productivity.

There is no cost to an open office plan that gives daylight access to a maximum number of employees. The payback is determined only by the cost and benefit of installing a daylight dimming system (usually in the 3- to 6-year range).

Additional Information

Key Words for Internet Searches
Daylighting, daylight harvesting, natural light, glare reduction, occupant comfort, skylights, clerestories, roof monitors

Series Matrix: Guide #5

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Guide
- High Relevance
- Moderate Relevance

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High-Performance Renovation: Electric Lighting

The Role of Electric Lighting

Because electric lights are generally on during working hours in City buildings, improving their efficiency even slightly is cost-effective, saves substantial amounts of energy, and reduces the associated pollution (1, 2). In renovations that combine cooling system upgrades (see Guide #8), better use of natural light (see Guides #4 and #5), and higher lighting efficiency, the initial size and cost of the HVAC equipment may also be reduced. Perhaps most important, properly designed electric lighting can increase productivity and improve morale by avoiding glare and by enhancing the visual quality of the lit spaces.

This Guide addresses interior lighting only; for exterior lighting please refer to Guide #1: Site Issues and Improvements.

Timing/Staging

Consider high-efficiency lighting early in the design process. In a typical design, the electrical service and HVAC equipment are sized according to an expectation of worst-case load conditions. In a “whole building” approach, electrical loads, HVAC, and the building envelope are designed together. By acknowledging early on that lighting will have high efficiency, it is possible to reduce HVAC loads and service size by assuming higher-efficiency lighting.

Consider dimming strategies early in the design process in cases where a reduction in peak load is possible. For well-daylit spaces that are not used for critical work, such as fully-glazed perimeter corridors, design for lighting to be dimmed or turned off during peak cooling periods. This, in conjunction with other energy efficiency measures, may allow a reduction in the size of cooling equipment.

Install quick payback measures.

Many measures can be accomplished without replacing light fixtures and without a need to re-circuit. Among these are:

- Remove unnecessary lamps in overlit spaces – but ensure that delamping does not create dark areas and that it does not reduce light levels below acceptable limits.
- Replace old luminaire lenses.
- Replace magnetic ballasts with electronic ballasts.
- Install occupancy sensors in all enclosed spaces (and consider them for open-plan spaces).
- Replace fluorescent exit lighting with light emitting diodes (LEDs).

Terminology

Ballast: Device used to start and operate an electric discharge lamp (e.g., fluorescent or high intensity discharge (HID)).
CFL: Compact fluorescent lamp.
Delamping: Process of removing lamps from fixtures.
DDC: Direct digital control. A control technique that uses electronic devices.
Glare: Discomfort of vision occurring when parts of the field of vision are excessively bright by comparison with adjacent areas.
Infrared radiation: Radiation emitted by bodies with low temperature, such as the furniture in the room or a person. The human eye cannot perceive infrared radiation.
Lamp: Device that emits light, such as what is commonly called an incandescent bulb or a fluorescent tube.
Lumen: The luminous flux emitted within a unit solid angle by a point source having a uniform luminous intensity of 1 candela.
Luminaire: Assembly of light fixture, lamp, ballast (if needed), and controls that are mounted on any of these parts.
Scotopic lumen: A measure of the intensity of light in the blue-green spectrum (wavelength = 507 nm). Only the rod photoreceptors of the eye are sensitive to this wavelength. The rod photoreceptors contribute significantly to the perception of brightness, and visual acuity for peripheral vision at low light levels (as opposed to cone photoreceptors responsible for central, high acuity vision).
T-8 lamp: Fluorescent lamp. “T” stands for “tubular,” while 8 stands for a tube diameter of 8 x 1/8th “ or diameter of 1”.
T-5 lamp: Same as T-8 lamp, but with a tube diameter of 5/8”.
Ultrasound: For the purpose of occupancy sensors, sound emitted in the 25-40 kilohertz range, a frequency that is much higher than can be perceived by humans.
The Role of Electric Lighting (cont’d)

Change lighting as part of a major renovation. In major renovations, new sources of natural lighting may be introduced or existing ones restored, glazing may change, and the mechanical system and ductwork may be re-engineered. This is an opportunity to completely revise the lighting system. Among the measures that should be considered are:

- Install dimming and other controls.
- Replace ambient lighting with a combination of ambient plus task lighting (3).
- Replace low efficiency luminaires with higher efficiency luminaires.


System Integration

Coordinate with glazing and natural lighting. Where natural lighting can substitute for electric lighting, circuiting and controls must be designed in conjunction with the design of the natural lighting. Likewise, the choice of glazing is closely linked with electric and natural lighting (see Guides #4 and #5).

Size HVAC equipment and ductwork in coordination with electric lighting. The heat output of lighting fixtures makes a substantial contribution to the cooling load (see Guide #8). In most large office buildings, areas away from the perimeter are cooled year-round. Efficient lighting saves energy both directly and by reducing the cooling load. These interactive effects can be studied using computer modeling (programs include DOE-2.1E and the more powerful EnergyPlus, currently under development).

Efficient Lighting Strategies

**FIXTURES, CIRCUITING AND DESIGN**

Replace Magnetic Ballasts and Re-lamp ($) (4)

All magnetic ballasts should be replaced, regardless of what else is done in the renovation. This should be combined with replacing existing T-12 lamps with T-8 lamps. In addition to electricity savings of about 40%, electronic ballasts do not hum and flicker like magnetic ballasts. Also, electronic ballasts can serve up to four lamps, compared to magnetic ballasts that serve only two. The City’s Municipal Energy Office has coordinated lighting upgrades in more than nine million square feet of facilities since its inception.

Recycle Lamps ($) Fluorescent lamps and ballasts contain glass, aluminum, steel, and copper which can be reclaimed for use in manufacturing other products. These items should always be recycled when they are replaced. Fluorescent lamps also contain mercury and are considered a hazardous waste. Certain ballasts contain PCBs and also threaten human health and the environment if they are not disposed of properly. *The cost of recycling is typically lower than the cost of having these components improperly disposed of.*
Efficient Lighting Strategies (cont’d)

Replace Fixture Diffusers ($)
Luminaires with acrylic or other diffusing or refracting lenses have a high brightness, giving the impression of a well-lit environment because they illuminate the adjacent ceiling. However, these lenses also cause glare (see Guide #5). Parabolic reflectors reduce glare; these reflectors are most effective if they are deep.

Install Efficient General-Lighting Fixtures ($$)
If existing fixtures need to be replaced, or if they are improperly spaced for a new use, it is desirable to replace them. The design of the fixture has a strong effect on the overall efficiency of electric lighting. The new fixtures should have electronic ballasts, preferably dimmable ones if natural daylight is available. If desired, indirect or combination direct-indirect fixtures can be used.

To even out light levels, two-lamp fixtures are often used instead of three- or four-lamp fixtures. In addition, T-5 lamps, because of a smaller surface area, are brighter, and should ideally be used in indirect or cove-lighting fixtures, and in places where their small size is an advantage, such as under-cabinet lighting.

Install Combination Indirect and Task Lighting ($$)
Tests have shown that lower light levels are acceptable when indirect lighting is used. Although indirect lighting is less efficient (because some of the light is converted to heat at the reflecting surface), many indirect lighting installations are designed to provide about 30°-40° footcandles for general office use. Task lighting (3) can be used in conjunction with indirect lighting, or with direct-indirect lighting, (3,6) to afford users glare-free control over both intensity and direction of lighting. Some fixtures provide a combination of direct/indirect lighting, reducing or eliminating the need for task lighting.

Install Efficient Point-Source Fixtures ($$)
A point-source reflector fixture (typically a downlight) is designed for a particular lamp type. Switching to CFLs may require replacing the reflector or the entire downlight, because a CFL is differently shaped than a typical incandescent lamp. One of the least energy-efficient types of incandescent downlights are those with reflector-flood or spot lamps, or with baffles that cut off most of the light to create a focused beam. While reflector-flood lamps provide a desirable kind of theatrical light, a CFL in a properly designed fixture can provide a very similar effect.

Re-circuit in Accordance With Use and Natural Lighting Patterns ($$$)
In most office buildings, the band of perimeter offices is circuited to allow local control of the lights in each office. When renovating a space, it may be cost-effective to do more than the minimum amount of re-circuiting, so that lights that share similar functions and have a similar relation to natural lighting are switched together. The circuiting should be designed to accommodate daylight dimming. The dimming equipment can be added at the same time or later, if the initial budget does not allow it.

Note: A once-popular measure was the use of three-lamp fixtures with the middle lamp circuited separately from the other two so three light levels could be achieved. This design reflected the limit of two lamps per magnetic ballast. Electronic ballasts can serve up to four lamps.

LIGHTING CONTROLS

Install Occupancy Sensors ($$)
An occupancy sensor switches lights off when no movement is detected within its range of sensitivity during a preset period of time (e.g., 15 minutes). Lights can be turned back on either automatically, when people re-enter the space, or manually. Payback periods are usually in the one– to three-year range.

• The automatic-off/manual-on method is appropriate for daylit spaces where electric lighting is not needed most of the time. For instance, an occupant could enter the office in the morning and not turn the lights on because the room is sunlit. An occupancy sensor that turns lights on whenever a daylit room is occupied would actually waste energy.

• The automatic on/off method is appropriate for spaces that do not receive natural light.

5 Courtesy, FineLight/ DOE/ NREL
Direct-indirect lighting

6 Courtesy, Brite-Lite
Direct-indirect lighting

7 Courtesy, Watt Stopper
Ceiling-mounted occupancy sensor

8 Courtesy, Watt Stopper
Wall-mounted occupancy sensor
Efficient Lighting Strategies (cont’d)

Other applications include occasional use in high-occupancy spaces, as well as smaller, enclosed spaces that have daylight dimming (see paragraph above for energy saving information about the latter use).

There are two sensor types: infrared and ultrasound.

- An infrared sensor registers infrared radiation emitted by objects within its view field. If the infrared image is not disturbed by sudden changes within a given period of time, a controller connected to the sensor sends a "lights-off" signal. Since infrared radiation can be blocked by any object, including, in most cases, glass, the infrared sensor requires a direct line-of-sight view that encompasses the entire coverage area.

- An ultrasound sensor can “see” anywhere in the space, because it operates on the principle of radar (or sonar). It emits high-frequency sound that is reflected back by objects in the space, forming a pattern. As with infrared sensors, if this pattern is undisturbed for a preset period of time, a controller sends a "lights-off" signal. Ultrasound sensors do not work well in spaces with large areas of soft surfaces that absorb sound, such as upholstered furniture and heavy drapes. In such instances, dual-technology that combines infrared and ultrasound sensing techniques provides the best result.

Sensor programming is flexible. Sensors can be programmed for up to half an hour delay before they turn off the lights, or circuited to work on a timer. They can be used in any enclosed space and also in public areas. For example, corridor lighting (except for emergency lighting) could be circuited with a timer that would keep lights "on" during the occupancy period, plus some additional time (e.g., one to two hours) before and after occupancy. During the remaining time, a timer could be set to turn lights off, and occupancy sensors could be used to turn them on in the unlikely situation that someone occupies the space.

Similarly, in situations where there are banks of lights in open office spaces, occupancy sensors can be used in conjunction with a timer to prevent operation during normal working hours, when shutting down banks of lights would be annoying to workers in adjacent areas. In this application, the sensors operate after working hours to turn lights off whenever the cleaning crew is not present.

Occupancy sensors can also be combined with other control technology such as daylight-responsive dimming and scheduling, either as local devices or as part of an integrated DDC system. Similar to most equipment options, sensors come in a range of quality levels, however, the technology is mature and reliable.

Install Outdoor Sensor-Controlled Lights ($)

Photocell control of outdoor lights is becoming commonplace (9). The photocell is usually mounted near the lamp, along with a separate controller. The controller often has a one-minute delay. The “deadband” that sets the limits above and below which the light is on or off is adjustable.

Install Timers ($-$-$$)

Timers can be distributed and independent, or part of central control systems. Central, timer-actuated control of building lighting can achieve substantial savings by automatically turning off lights (except those on emergency circuits) throughout a building at times when only a few occupants are likely to be in the facility. Typically, the system gives a warning before turning off – e.g., by flickering the lights. The occupants can call the central operator to ensure that lighting remains on in their area (strategy implemented in large buildings, with 24-hour maintenance crew), or can press an override control that will allow lighting to remain on for a preset time (e.g., two hours).

In apartment buildings, all non-emergency corridor lighting can be turned off late at night by a timer, and turned back on with motion sensors, should anyone arrive during that time period.

Install Load-Shedding Controls ($$$$)

The City can reduce its electricity demand charges by turning off selected lighting during peak load periods (10). For occupied spaces, consider shedding the load by dimming instead of switching, if possible. One downside of the load-shedding strategy is that the peak load may coincide with a sudden afternoon thunderstorm, when maximum lighting would be desired.

Install Daylight Dimming Equipment ($-$-$$-$-$$)

A daylight dimming system adjusts the light emitted by lamps to maintain a certain footcandle level on the work plane or on another surface of interest, such as on the floor of a corridor. Payback periods are usually in the three–to six-year range.
Efficient Lighting Strategies (cont’d)

Dimmable electronic ballasts can dim down to approximately 10% of full light output, which corresponds to about 18% of the electric rating. Some of the ballasts dim down to 5% or 1% of full light output, but costs increase significantly.

The light sensor, which is usually mounted on the ceiling, conveys a signal to a controller. The controller adjusts the output of a dimmable ballast, which in turn causes the lamps to produce more or less light, as needed.

The controller needs to be calibrated during installation because the light received by the ceiling-mounted sensor is usually somewhat different from the light received on a desktop. This is an easy process that only requires a portable light meter.

In a daylit space, natural light fluctuates from hour to hour, day to day, and season to season. If the windows or skylights are large enough, there will be very little need for electric lighting during extended periods of time. The daylight dimming system modulates the electric light gradually, compensating for the ebb and flow of natural light in a way that is imperceptible. Thus, the occupants always have good quality light while saving energy.

All daylight dimming systems have a built-in delay, to avoid changing the light output at the passage of every cloud.

Two types dimming equipment are available:

- **Stand-alone dimming**: A photocell senses the light level and signals a controller mounted in the same unit to dim up to 50 to 80 ballasts, depending upon the manufacturer.

- **Separate photocell and controller**: A similar but somewhat more flexible system separates the controller from the photocell, allowing the integration of the controller in a multi-functional module. This module can be used to manually dim the lights or to turn the dimming feature off for a preset period of time, as may be required during relamping (see below). The module can also be used to provide feedback to a central EMS. These additional features increase the first cost of the system.

Operation issues. Some lamp manufacturers recommend that lamps not be dimmed for their first 24-100 hours of operation. To address this issue, a wall switch can be wired to disconnect the controller from the ballast. Of course, someone has to remember to turn the dimming feature back on after the burn-in period. A second option is to use a multifunctional control module. This wall-mounted module has a button that can be pressed when the lamps are changed. Pressing the button surpresses the dimming and triggers a countdown that will restore the dimming function after a preset period (usually 24-100 hours). In general, such modules also give the option for a manual dimmer that the occupant can use to adjust the maximum light level allowed in the space.

Even if the daylight dimming system doesn’t provide for a burn-in period, the energy savings will more than compensate for any reduction in lamp life.

*Maintenance needs are minimal* – just keep the photocell relatively clean. If the photocell gathers dust, or if it is disabled, the system will dim less than it could, or will not dim at all. This will affect the energy savings but will not diminish the amount of light to the space (there will be more light than needed, not less).

**Install equipment for stepped daylight control ($$–$$$_$$)**

A fully-glazed space rarely needs electric lighting during the day. All or some of this electric lighting could be turned on and off automatically, based on a photocell sensor, if the function of the space is not significantly affected by the sudden (albeit infrequent) change in light level. To avoid annoying on/off flicker, all stepped daylight control systems have an adjustable deadband and adjustable on-off delays.

Examples of potential applications include spaces that are fully glazed and with temporary occupancies, such as perimeter corridors, atriums and greenhouses. Do not employ stepped automatic controls in spaces occupied by the same people for extended periods of time, such as offices. These spaces can experience lower electricity use by manual switching of multiple lighting circuits.

*Three-step control*. At a preset light level, a first group of luminaires is shut off (e.g., those closest to the glass). As the light intensity increases, a second bank of luminaires is deactivated. In the third step, all luminaries are off. Re-activation occurs in reverse order: the luminaries that were last turned off are first turned on.

*On-off control*. A sensor and controller shut off and turn on all lighting in a space (or all lighting controlled by the system, which could be only the bank of luminaires closest to the glass).

Stepped daylight control is less expensive to implement than continuous dimming control, because it eliminates the need for dimmable ballasts.
Efficient Lighting Strategies (cont’d)

Install Integrated Light Control Equipment (SSSS)
Several manufacturers offer light management systems that are connected into a zonal, or into a building-wide DDC system. Using local control panels, or a central control computer, operators can easily track and control the light in all spaces, for all fixtures. Features include:

- Scheduling
- Occupancy sensors
- Daylight-responsive dimming
- Manual dimming and on-off controls
- Individual fixtures that are computer-controlled by the occupant

The Digital Addressable Lighting Interface (DALI): DALI is a manufacturer-independent standard that defines a digital interface for the communication between the individual components of a lighting system. This guarantees the exchangeability of dimmable ballasts from different manufacturers and provides flexibility in the design, installation, and maintenance of lighting management systems. Although this is a relatively new standard, DALI-compatible lighting components are available, with more coming on the market in the near future. This technology is expected to grow fast and will allow such features as dynamic individual or group addressing of luminaires for automated lighting control, without special requirements for wiring of luminaires for group addressing.

LAMP STRATEGIES

Relamp Hard-to-Reach Fixtures with Long-Lived Lamps ($) (11)
High fixtures (for example, downlights at the ceiling of a tall lobby), or other fixtures that are hard to relamp can profitably be relamped with fluorescent lamps, which last considerably longer than incandescents, with energy savings as an added plus. Consider electrodeless lamps, which are described below. Although expensive, they have a very long life.

Replace Fluorescent Exit Lighting With Light Emitting Diodes (LEDs) ($) (12)
LED technology can offer the same sign brightness as fluorescent lighting at much lower electricity use and over much longer periods (LEDs last for 12 or more years of continuous burning). In addition, LED lamps are extremely sturdy. Note, though, that LED lamps are not as efficient as fluorescent lamps for space lighting.

Install T-8 or T-5 Lamps ($-$$) (13)
As part of the switch to electronic ballasts, use either T-8 or T-5 lamps. T-8s deliver 80 to 95 lumens/watt (L/W) compared with 50 - 65 L/W for the older T-12s used with magnetic ballast fixtures. T-5’s deliver 85 to 100 L/W. Because they are smaller, they have a higher surface brightness and can create glare in direct lighting fixtures. They are therefore used primarily in indirect fixtures, or where a thin profile is desired. T-8s and T-5s can be dimmed if dimmable electronic ballasts are specified.

Install High Scotopic Lumen Lamps ($) (14)
High scotopic lumen lamps are simply T-8 lamps that operate at a higher temperature (e.g., about 4000K or higher), and as a result emit light that is closer in feel to natural light on a cloudy day. The human eye is adapted to daylight. If a regular T-8 lamp and a high scotopic lumen lamp illuminate a surface with the same light level, as measured in footcandles with a regular light meter, the light cast by the high scotopic lumen lamp appears much brighter and also cooler. The extra brightness can be taken advantage of in several ways:

- In a large renovation project, the number of fixtures can be reduced by about 20-30%.
- For existing three-lamp fixtures or four-lamp fixtures, the regular T-8 lamps can be replaced with two and three high scotopic lumen lamps, respectively.
- High scotopic lumen lamps can be installed in existing fixtures, replacing all existing T-8 lamps, and be dimmed with a daylight dimming system.

Daylight dimming applications are particularly suited for these lamps, as their light color is much closer to the daylight color than that of regular T-8s.

These lamps are sometimes marketed as high-temperature lamps. Ensure that the lamp has high scotopic lumen output. The cost of the lamps is about four times higher than that of regular T-8s, but their use actually reduces first costs in a major renovation project where the light fixtures are replaced. In other instances, the lamps have an attractive payback given the significant energy savings.

Install Compact Fluorescent Lamps (CFLs) ($-$$) (14)
CFLs are a rapidly evolving technology, and many types are now available. The latest-generation CFLs are also dimmable. They yield 55-65 L/W. The best of these provide reasonable color balance, especially when used in a downlight can, where
Efficient Lighting Strategies (cont’d)

the light can be tempered by the color of the reflector.

CFLs with an integral ballast and screw socket can directly replace incandescent lamps. Alternatively, less expensive lamps without ballasts have pin connectors. These connectors insert into a fixed ballast that is part of the fixture, or in a separate ballast that is screwed into an incandescent socket. If CFLs are used in fixtures designed for incandescent lamps, the overall efficiency may drop.

In many downlight fixtures, the reflector assembly can be replaced to match the lamp without the need to replace the entire fixture.

Install Electrodeless Lamps ($$-$$$)

A fluorescent lamp is a form of gas-discharge lamp that requires an electrode at each end. This reduces lamp life and causes fluorescents to operate poorly in cold locations. Mercury- or sodium-vapor gas-discharge fixtures operate well outdoors, but have poor color rendition. The metal halide lamps (high-intensity discharge, or HID) commonly used to improve color rendition have a relatively short life.

The “electrodeless” lamp is a relatively new type of gas-discharge lamp with an output spectrum similar to fluorescents and a comparable efficacy (60-75 L/W). Because it discharges without an electrode, it has a longer life and works well in cold locations.

Lifecycle costs are comparable to or better than metal halide lamps. While the lamps cost over $300 each, they last six times as long as metal halide lamps. An analysis extending over the life of the lamp (10 years if on all the time, 20 years if on half the time) shows that electrodeless and metal halide lamps have a comparable cost. For lamps in hard-to-access locations, however, the lifecycle and maintenance costs associated with the electrodeless lamp could be much better. The City installed this technology in the lobby of the Municipal Services Building more than 5 years ago and the lamps are performing as expected.

Benefits

- **Comfort**
  A reduction in glare alone is sufficient reason to replace light fixtures with new, more efficient units. Indirect (or direct/indirect) lighting can improve a sense of comfort, as can the availability of task lighting. Metal halide and electrodeless exterior lamps can avoid the color imbalance typical of less expensive gas-discharge lamps.

- **Energy Savings** (15)
  Efficient electric lighting not only saves energy directly; it also reduces the cooling load and can allow the downsizing of cooling equipment (see Guide # 8). Dimming systems can lead to extra energy savings by themselves or when coupled with natural lighting (see Guide #5).

- **Reduced Emissions**
  Reducing electricity use (both for lighting and for cooling) reduces off-site emissions, including CO₂, SO₂ and NOₓ from power plant operation.

- **Resource Conservation**
  Mercury is a recoverable and reusable trace metal used in fluorescent lighting technology. If leached into the soil (e.g., from landfills) the trace metal can accumulate in the food chain, causing serious neurological disorders in humans and animals. While the mercury content in fluorescent lamps has been decreasing over the past 20 years, the EPA still classifies conventional fluorescent lamps as hazardous waste. **Lamps should be sent to lamp recycling companies that handle mercury recovery, not landfilled.**

  For new fluorescent lamp purchases, several major US lamp manufacturers now manufacture “low-mercury” lamps that meet the EPA’s classification for non-hazardous waste and do not have to be handled specially.
Life-Cycle Assessment (cont’d)

Light fixtures become obsolete in design and are replaced as part of a renovation. A lifetime of 25 years is a reasonable average for interior and exterior fixtures. During this period, they tend to become slightly less efficient because of a buildup of dirt on the reflectors. It is possible to replace parts of a fixture (typically the diffuser and the ballast) while leaving the rest in place. Thus, the fixture housing may last for 50 years, during which time it might be moved several times.

Lamps have a much shorter life, and their output (efficacy) declines – lamps are rated for their expected output at 70% of their expected lifespan. In the period when they are operating above their rated output, they may be dimmed to reduce energy. The regular need to replace lamps allows the periodic substitution of upgraded, higher efficacy lamps as they become available in the marketplace (typically in association with replacing ballasts and improving controls).

While a life-cycle cost analysis should be considered when lighting is upgraded, along with other elements (typically glazing and cooling), it is usually sufficient to use simple payback calculations for lighting-only renovations – the payback period tends to be very attractive.

It is always cost-effective on a simple payback basis to replace existing T-12 lamps and magnetic ballasts with T-8 lamps and electronic ballasts. Replacing fluorescent exit light fixtures with LEDs is equally cost-effective. While it is difficult to define the cost benefit of the productivity and morale improvements resulting from reduced glare, it is safe to say that any upgrade of fixture diffusers that noticeably reduces glare is cost-effective, and may be necessary for certain functions. Many older spaces are greatly overlit, and removing unnecessary lamps can have a very short payback.

Occupancy sensors are always cost-effective in enclosed spaces with low-occupancy, where most estimates assume savings that average 30%. They are also highly effective in intermittently occupied spaces such as bathrooms, conference rooms, and storerooms. A cost analysis is required to verify the cost-effectiveness of occupancy sensors in open spaces.

Timers can be used effectively in various ways, often in conjunction with occupancy sensors, to schedule lighting control strategies, such as between working hours, cleaning hours and unoccupied hours. Dimming controls can be used in any space that has access to natural light, especially when reglazing and natural light enhancement measures are installed at the same time.

Perform a life-cycle cost analysis to determine the cost-effectiveness of more expensive options, such as recircuiting, replacing fixtures, substituting a combination of indirect ambient lighting and task lighting for direct ambient lighting, and installing light management systems. This analysis should take account of changes in glazing, daylighting, cooling, and HVAC control.

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Additional Information

Key Words for Internet Searches
LED, occupancy sensor, dimming, electronic ballast, compact fluorescent lamp, CFL, digital addressable lighting interface, DALI, electrodeless lamp

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High-Performance Renovation: Heating System Upgrades

The Role of Heating Systems

Many older public buildings were constructed with little or no insulation, and with large and often leaky windows. A heating system with a large (possibly asbestos-encased) boiler was key to providing warmth and comfort within the building, while also being responsible for producing hot water. In many cases, the original heating fuel used was coal, then oil.

As these buildings are renewed and their central heating systems are upgraded or replaced, several design alternatives need to be evaluated, including a possible switch of heating fuel type. In all cases, however, the capacity of the system should be sized to acknowledge reductions in building heat loss that may have occurred during previous retrofit projects (e.g., an earlier window replacement) or that are part of the current renewal or renovation project.

Timing / Staging

Decide on all improvements to roofs, walls, and windows and skylights, before finalizing the heating system design. Sometimes it is cost-effective to invest in increased conservation (e.g., high-performance windows) in order to reduce the size of heating-system components (boilers, and even pumps and piping). This strategy results in a more attractive return on investment and improves building comfort.

In some cases, reducing heating loads may allow for the installation of smaller boilers in tight spaces of renovated structures.

Site work. Sport fields may require excavations over large areas. This is an opportunity to lay horizontal piping for a closed loop geothermal heat pump system. Parking lots can be used in a similar manner, but the pavement will keep the soil underneath relatively dry, reducing the efficiency of the horizontal geothermal system. A horizontal system is not the only option; the large open areas of both sport fields and parking lots allow for easy location of geothermal wells.

Terminology

AFUE: Annual Fuel Utilization Efficiency. Rating that accounts for results from several tests, and that attempts to approximate the performance of a furnace under a range of full-load and part-load conditions, as may be encountered in actual operation.

Boiler: Combustion heating appliance that uses water as the heating medium.

Btu: British Thermal Unit. A small unit of heat that is equal to the amount of heat it takes to raise one pound of water one degree Fahrenheit -- about the amount of heat contained in a wooden kitchen match.

Cogeneration: Production of electricity and heat (in the form of steam or hot water). Also known as “combined power and heat systems.”

Combustion Efficiency (Ec): Measures the efficiency with which the burner of a boiler or furnace converts fuel to heat. It is a ratio of Btu output to Btu input. Because it does not account for heat losses from convection and radiation, combustion efficiency is always higher than thermal efficiency.

COP: Coefficient of Performance. Rating of efficiency that, for heating, equals the ratio between heat (energy) output and heat (energy) input. Water loop heat pumps with a heating COP of 3 deliver 3 Btu heat for every 1 Btu of energy input.

Furnace: Combustion heating appliance that uses air as the heating medium. Mostly used in relatively small buildings.

MBtu: Thousands of Btu.

MMBtu: Millions of Btu.

Microturbine: Small-scale cogeneration equipment that typically produces 30 to 400 kW electricity at 20-30% efficiency. If the co-generated heat is also used, the combined efficiency can increase to 40-60% or even higher. The high-speed (up to 100,000 rpm) electric generator system includes the turbine, compressor, shaft-mounted generator, and the electronics for delivering AC power.

Service hot water: Hot water produced for uses other than heating, such as lavatories, showers, kitchen, laundry. In residences this is referred to as domestic hot water.

Steam trap: A device in a steam heating system that prevents steam from escaping, while removing condensate and air.

Thermal Efficiency (Et): Also known as “boiler efficiency” or “overall efficiency” is the energy output divided by energy input of the boiler or furnace, as defined by the American National Standards Institute (ANSI) Z21.13. Thermal efficiency accounts for the combustion efficiency (Ec), and also for radiation and convection losses. It gives a more complete picture of boiler efficiency than the combustion efficiency.
The Role of Heating Systems (cont’d)

System Integration
When renovating a warm-air heating system in a building that is only heated, consider introducing mechanical cooling too (if the building function would benefit from it). In typical situations, cooling requires two to four times more air than heating, therefore, the existing ducts can serve to temper the space in summer. However, comfort cooling can be extended for most of the year if the cooling load is minimized with a highly efficient lighting system, ENERGY STAR office equipment, and glazing that is well shaded and/or has low solar heat gain.

Scale of Importance

1. Plan first. The time spent on planning is saved many times over during operations. Sometimes it costs less to make major changes than numerous small repairs, or several issues can be addressed at the same time – such as an indoor air quality problem and a comfort problem.

2. Remedy conditions that create safety or health hazards. Older installations may have a variety of problems, such as a corroded flue that leaks carbon monoxide into the building, a chimney top that is located too close to windows, defective pressure relief valves, or exposed asbestos.

3. Remedy conditions that threaten the integrity of the building. Again, older installations may have many defects:
   - If a hot-water boiler fails during peak heating, the pipes could freeze and burst, damaging the entire building.
   - Boilers and pipes that leak create unsafe and possibly unhealthy conditions. Further, water can seep into walls and travel, deteriorating finishes and structure. Leaks also creates conditions that are favorable for mold growth.

4. Remedy conditions that create environmental hazards, such as leaky oil tanks.

5. Improve the indoor air quality (IAQ) inside and outside the building. For example:
   - Sometimes soot and odors permeate areas adjacent to the boiler room. Even if there is no carbon monoxide pollution, the condition must be remedied. A smoke test, which may be coupled with air pressurization of the boiler room, can indicate the migration pathways for the air from the boiler room to other areas.

6. Perform other deferred maintenance. This can affect not just comfort, but also IAQ. For example:
   - In steam-to-hot-water systems, clean the heat exchangers. It is not uncommon for heat exchanger efficiencies to be reduced from the original 90% or higher to 70% or lower because of dirt and dust.
   - In steam systems, repair faulty condensate traps.
   - In hot water systems, repair valves; in air systems, repair air boxes.

7. Provide programmable thermostatic control for the heating system (2). Some buildings have unnecessarily high energy costs because they rely on a minimal temperature control system. In this scheme, the hot water temperature is adjusted according to the outside air temperature. There may or may not be separate water loops by orientation (e.g. east, west, south, north).

Minimal adjustment of the hot water temperature for an entire façade cannot fully account for variations in solar load, lighting heat gain, and number of people. The situation is even more acute if several façades are served by a single loop. The result can be overheating of some zones where space temperature is then adjusted by opening windows.

A more effective control method is to install a programmable thermostat in each regularly occupied room that needs heating or, alternately, a Building Management System (3) could be programmed to control the temperature in each such room (or group of rooms).
The Role of Heating Systems (cont’d)

8. Seal and insulate ducts, insulate pipes. For furnace systems, duct leakage results in higher energy losses than an inefficient burner. Seal both supply and return ducts. Insulate supply ducts, and if return ducts are located in unconditioned areas, insulate them as well. For boiler systems, insulate the pipes. Caution: If the hot water pipes (or hot air ducts) are the primary heat source in an unconditioned space, consider simultaneously insulating any potable water pipes or sprinkler pipes in that space.

9. Increase the efficiency of boilers or furnaces. This can be achieved by replacing all equipment or specific parts. Avoid excessive oversizing; it wastes energy and can actually reduce comfort. See the section "Heating Retrofit Strategies" below. Refer also to Guide #9: Controls and Building Automation.

10. Consider heat recovery from boilers. Options include stack gas heat-recovery equipment (such as air preheaters) and water-recovery equipment to re-use heat from blowdown of steam boilers.

11. Consider condensate recovery from steam systems. Retrieving heat from steam condensate can be used to preheat domestic hot water. Condensate water can be directed to cooling towers, irrigation, or toilet flushing (Note: Check chemical treatment needs of cooling tower water. Depending on water quality and chemical treatment type, the cooling tower may operate well with a mix of condensate/potable water, but may require increased maintenance with pure condensate water).

12. Consider replacing the entire heating system. If the building undergoes a complete renovation, it becomes possible to replace the entire HVAC system. This opportunity is rarely encountered. For air systems, consider adding cooling at the same time (or at least size the new ducts to perform cooling at a later date).

Heating Retrofit Strategies

This section addresses strategies that can be employed with three types of equipment: primary heating equipment (boilers, furnaces, chiller/heaters, geothermal heat pumps, and others); distribution systems (fans, ducts, air boxes; and pumps, pipes, coils); and other energy-saving devices.

BOILERS

Equipment is available in a variety of configurations; each type has particular advantages and disadvantages. This guide comments only on those aspects that affect energy efficiency and other sustainability aspects, such as pollution or waste. Regardless of type, all boilers can use less energy by implementing the strategies below:

Right-size the New Boilers to Meet the Design Heating Load ($-$$$)

The right load will be in accordance with guidelines by ASHRAE Standard ASHRAE 90.1-2001. This is critical for buildings served by a single boiler (4). While it is usually permitted to oversize up to 30%, that factor should not be applied to a heating load that is also overestimated (usually because the calculations are very rough). The effect of oversizing is reduced, but not eliminated, for boilers with modulating flame control.

For installations with two boilers, size each boiler to 67-

80% of the peak load, depending on how critical it is to maintain comfort conditions in all spaces. If one boiler fails, the other will meet the entire load except during very cold weather; in case of failure under peak heating conditions, some spaces that are not always occupied can be left with lower temperatures (e.g., storage, circulations, even cafeterias).

A modular boiler plant (5), with four or more smaller-capacity boilers, provides redundancy without significant oversizing. The boilers can be brought into the central plant on hand-trucks – an advantage for some renovation projects. The modular boiler plant can be of particular interest in buildings where the load changes frequently due to occupancy patterns, such as occasional use of the gymnasium, and where there is a need for redundant equipment (making them preferable to single, modulating flame boilers).

Modular boiler plants can be more efficient than single-boiler or two-boiler installations because modular boilers track the heating demand more closely. Modular boiler operation can actually be fairly inefficient at low load if hot water circulates through all boilers at all times. To correct for this, design the piping scheme to bypass boilers that are off, and minimize standby losses and use of electricity for pumps.
Heating Retrofit Strategies (cont’d)

In older buildings where all hot water demand is met by operating the heating system boilers, consider a separate “summer” service hot water boiler to address the situation. Left-as-is, the operation leads to very inefficient operation of the boilers during summer, especially in office buildings, where demand for hot water is intermittent and constitutes only a small fraction of winter load. A heating boiler can cycle on/off so often as to result in an efficiency of 25 - 30%. There are two instances where the use of heating boilers during summer can be energy efficient, and a separate summer boiler is not needed:

- A modular boiler plant produces both heating and service hot water. In summer only one boiler operates.
- The boilers have a modulating flame and the service hot water system utilizes a storage tank. In summer, one of the boilers operates at low part-load, but the modulating flame reduces the heat loss. The boiler does not need to cycle often because it charges the hot water tank.

Equip Boilers With Modulating Flame Burners ($$-$$$)

These burners can be retrofitted to existing boilers, and should be specified for most new boilers. Frequent on/off cycling of boilers results in higher energy use two reasons: (a) a boiler reaches its rated efficiency only several minutes after startup, and (b) a boiler loses heat to its surroundings and up the flue during standby periods. Boilers with modulating flame burners closely match heating loads, which minimize on/off cycling and results in the lowest energy cost. For small boilers where the modulating flame control is either unavailable or prohibitively expensive, use three-position burners (low-medium-high). Two-position burners (low-high flame) are also available, sometimes at a somewhat lower first cost, but the premium paid for the three-position setup is quickly recouped in lower energy costs. Whenever possible, avoid on/off boilers.

Consider an Automatic Shutoff Damper for the Flue ($-$)$

This technique reduces standby losses, and is most effective with non-condensing boilers. Non-condensing boilers exhaust air at relatively high temperatures. This heat is lost and boiler efficiency suffers, but the warm air does not condense inside the flue. Traditional materials and methods are adequate for flue construction.

Install High-Efficiency Non-Condensing Boilers ($)

The following recommendations from the U.S. Department of Energy’s, Federal Energy Management Program (FEMP) cover conventional (non-condensing) low- and medium-pressure boilers used for commercial space heating applications. Rated capacities are in Mbtu/h (thousands of Btu per hour). “Best Available” efficiencies do not include condensing boilers, which have efficiencies greater than 90% (see below). Consider purchasing boilers with best thermal efficiency for each category. Note that residential boilers (below 300 Mbtu/h) are separately rated (using similar AFUE ratings).

Consider Dual Fuel Burners ($$-$$$$) (6)

Some old boilers are fired with coal – inexpensive but highly polluting. Natural gas is the replacement of choice. For larger facilities, consider a dual-fuel system that uses natural gas most of the time, but switches over to fuel oil when justified by price or required by contract with the gas utility. These systems qualify for favorable natural gas rates because they are switched to oil upon the request of the gas utility.

Install Condensing Boilers ($$$$-$$$$$) (7)

Condensing boilers achieve a thermal efficiency higher than 90% by using an additional heat exchanger to wring more heat from the gases that ultimately pass thorough the flue. These gases become cool and the water vapor contained in them condenses. The flue must be corrosion-resistant. It can be made of plastic if used exclusively with condensing boilers, but if shared with other boilers that exhaust higher-temperature gases, or if plastic is not allowed by codes, the material of choice is usually stainless steel. In any case, the condensate water must be discharged to a drain. Commercial condensing boilers are currently manufactured in sizes 0.3 to 3.3 MMBtu.

Some condensing boilers use modulating flame control and, because of the specifics of the heat recovery process, are more...
Heating Retrofit Strategies (cont’d)

efficient at part-load ratio than at full load — actually they are most efficient at the lowest part-load at which they can operate (usually 10 - 30%). This is advantageous, because most buildings experience loads that are much below peak for most of each year. The advantage is most pronounced in buildings with one or two boilers that usually operate at a low fraction of their capacity, but this advantage remains significant even in modular boiler installations.

Because of the low temperature flue gas, condensing boilers can be vented through the wall, eliminating the need for a chimney — but side venting is unacceptable if windows or doors are above or close to the exhaust point.

Historic preservation projects are often a good application for the condensing boiler technology because the mechanical space is limited and access to the boiler plant restricted.

Large conventional boilers are often difficult to bring into the building. Cast-iron boilers can be assembled on-site from individual modules, but this is expensive and time-consuming. A modular condensing plant often requires less space than the non-condensing counterpart and, for the same rated input, a condensing boiler outputs approximately 8-20% more heat, offering an energy-efficient solution.

Historic preservation projects with limited mechanical space and restricted boiler place access, therefore, are often a good application for the condensing boiler technology compared to the larger conventional boilers that can be difficult to bring into a building.

Caution: Condensing boilers need low return water temperature; otherwise they function like conventional boilers. If the entire heating system is replaced, design appropriately. If only the boiler plant is replaced, check whether the water flow can be changed to obtain the desired return temperatures.

Consider Steam System Conversion ($-$-$$$)
When planning to renovate a building heated with steam, determine the condition of the distribution system. Often condensate return lines are clogged with deposits and greatly reduced in functional diameter. If this is the case, conversion from steam to a hot water (hydronic) heating system should be considered at the time of renovation (system conversion subsequent to building renovation results in high costs related to the inaccessibility of the heating system distribution lines).

Install an Oxygen Trim Control System ($$$-$$$$)
This strategy will improve the combustion efficiency of both oil and gas burners, and is estimated to save 2-5% in fuel use per year (see Guide #9: Controls & Building Automation).

Increase Insulation for Boilers, Hot Water Pipes, and Steam Pipes ($$$-$$$)
Note that beyond a certain point, additional pipe insulation saves no energy — optimal thickness can be calculated.

FURNACES
Small buildings have residential-type heating systems (furnaces) and through-the-wall, packaged air-conditioners. Larger systems use rooftop DX units that have an integral furnace. In all cases, the typical furnace has about 80% thermal efficiency. Sometimes the efficiency is rated as AFUE, and that figure is typically smaller than the thermal efficiency. In addition to condensing and modulating flame furnaces, consider the following strategies to improve the efficiency of furnaces that cycle on-off:

Automatic Shutoff Damper for the Flue ($-$$$)
This technique reduces standby losses, and is most effective with non-condensing furnaces.

Seal and Insulate the Rooftop Units ($-$$$)
Air leakage into these units can increase the outside air intake by 15 - 30%. Heat loss through the jacket is another concern.

Install Insulation ($)
Seal and insulate ducts in hot air systems — whether the hot air is provided by a furnace or by a central boiler that circulates water to heating coils. See discussion on leaky ducts in the section "Scale of Importance."

OTHER HEATING SYSTEMS

Absorption Chiller/Heaters ($$$-$$$$$) (8)
See Guide #8: Cooling and Ventilation Systems for a discussion on absorption chillers. With the addition of a heating module, the absorption chiller becomes a chiller/heater. During periods of cooling, the equipment produces hot water using heat rejected by the chiller. During periods when the entire building requires heating, the heating module operates like a boiler with 80% efficiency. The setup is most effective where there are extended periods with simultaneous need for both cooling and hot water. Hot water may be
Heating Retrofit Strategies (cont’d)

needed for heating, domestic uses, kitchen, laundry. The energy efficiency measures recommended for boilers usually apply to the heating module of chiller-heaters as well.

Geothermal Heat Pumps ($$$$)

See Guide #8: Cooling and Ventilation Systems, for a discussion on geothermal heat pumps. In general, geothermal heat pumps are more attractive in cooling mode than in heating mode, because in heating mode, the system incurs the cost of demand charges. Higher temperature heat can be extracted from a body of water, water well (open loop system), or standing column well than from a closed loop (9) that is in contact only with the ground. It is possible to size a closed loop so that it yields similar temperatures with those obtained from a standing column well, however, it is more expensive. When compared with a non-condensing boiler system, geothermal heat pumps can provide heating for lower cost, but are often more expensive to run than a condensing boiler system – unless the building has simultaneous heating and cooling needs.

District Steam Reduction ($)

District steam is very attractive where available, because it eliminates the need of a heating plant. Ensure that the heat exchanger is regularly cleaned. Scaling can reduce the efficiency of steam conversion from 90% to about 70%.

Air-to-Air Heat Pumps ($$-$$$

Air-to-air heat pumps provide cooling by rejecting heat to the air, much like an air-cooled rooftop DX, and extract heat from the air for heating. Heating COP depends very much on outside air temperature; below 30°F the COP drops quickly. To prevent coils from freezing, when the temperature dips to approximately 30°F, the pumps periodically run a reverse cycle (taking heat from the room to defrost the coil) or provide heat to the coils with electric resistance. Normally the heat pumps can operate to 20°F or even below, but the air they deliver feels cool. For this reason, the heat pumps in most systems switch to electric resistance heating around 30°F.

In the final analysis the heating season operation occurs at a COP that averages around 1.5 – that is, the operation is about 50% less expensive than that of electric resistance heating. Heat pumps, however, are more expensive to operate than a boiler/DX combination. For this reason, the air-to-air heat pumps are attractive in smaller buildings that need cooling, and where natural gas is unavailable.

Electric Resistance Heating ($-$)

Electric resistance heating should be avoided as a rule, but may make sense in limited situations. For example, a well insulated building with large internal loads (perhaps from computer use) that result in infrequent heating needs could use electric resistance heating. This specifically refers to buildings with exceptional shells, glazing that has U=0.2 or below, walls where thermal bridges have been mitigated, and very well insulated roofs.

HEAT RECOVERY DEVICES

The most common types of heat recovery devices extract heat from exhaust air. Plate air-to-air heat exchangers, heat pipes, and glycol loop systems are more often specified than enthalpy wheels, and are described below (see Guide #8: Cooling & Ventilation Systems for a discussion on the latter; enthalpy wheels are of particular interest during the heating season if the building is humidified). Heat is also recovered from steam systems. More infrequently, heat is recovered from the hot gas exhausted by the flue stack. This is usually cost-effective for high-temperature flue exhaust that is not commonly encountered in commercial applications.

Recover Heat From Exhaust Air ($$-$$$)

The devices described in this section recover sensible heat from the exhaust air. Sensible heat is the heat associated with a change in temperature. In winter when the air temperature is low, sensible heat recovery devices can be effective. In summer, however, the heat temperature in Philadelphia does not reach high values except for very brief periods. As a result, sensible heat recovery devices are generally ineffective in summer and should be bypassed during this period. (See enthalpy wheels in Guide #8 for a heat recovery strategy that can be beneficial in summer.)

A plate air-to-air heat exchanger (10) takes in outside air through one half of a box and exhausts building air through the other half. The air stream passes through fins or channels that separate the box. Heat is easily transmitted across the two sides. Exhaust air releases heat in the process; intake air captures that heat. The heat exchanger efficiency is usually 50-70%.

Heat pipes are tubes filled with refrigerant that cross the boundary between the two halves of the box. The heat transfer cycle is as follows: The refrigerant starts in liquid form in the tip of the tube that is located
Heating Retrofit Strategies (cont’d)

in the exhaust air stream. It absorbs heat, evaporates, and migrates to the tip that is bathed by the cold, intake air stream. There it condenses, releasing the heat, and flows back to the exhaust side.

Glycol loop systems are used where the air exhaust is located far from the outside air supply – a common occurrence. A pump moves glycol between a coil located in the exhaust air stream, where heat is extracted heat, to a coil located in the intake air stream, where heat is released. The heat exchanger efficiency is usually 50-65%.

To be cost-effective, these air-to-air heat exchangers require a high fraction of outside air (e.g., as may be encountered in assembly spaces) and a means to be bypassed in summer. The reasons are as follows: the cost of heat recovery equipment is too high for small outside air quantities; and the heat recovery device increases fan electricity use and demand, as well as the heat released by the fan. In summer, this results in a net increase in energy cost, because the air in Philadelphia is not hot enough to yield much benefit.

Recover Heat From the Blowdown of Steam Boilers and From Water Return Condensate ($-$-$)

A steam-to-water or water-to-water heat exchanger can recover this heat and use it to preheat service hot water.

ENVIRONMENTAL ISSUES

Use Environmental Materials

Boilers are manufactured of cast iron and steel. Because cast iron equipment lasts much longer than steel, it has a lower impact on resources, assuming that both the steel and cast iron equipment have the same efficiency. However, the high-efficiency condensing boilers are currently available only in steel.

Refrigerants used in heat pumps continue to improve. While hydrochlorofluorocarbon (HCFC) refrigerants are less damaging to the ozone than chlorofluorocarbons (CFC) refrigerants, hydrofluorocarbon (HFC) refrigerants result in zero ozone depletion and are the preferred choice for use in heat pumps.

Most acoustic duct liners are manufactured with glass fiber; some are now available with natural fibers. Consider protecting these liners with perforated sheet metal. This is an expensive but worthwhile measure.

Reduce Construction Waste

Steel used for boilers and furnaces and for sheet metal has at least 20% recycled content. Insulation for piping and ducts can have recycled content of 5-80%.

Benefits

- **Comfort**
  Greatly oversized heating systems are more likely to produce uncomfortable temperature swings within a building. Right-sizing diminishes this problem while decreasing first cost and energy cost.

- **Energy Savings**
  Heating accounts for 10-30% of the energy cost in many air-conditioned building types. If the cost of electricity for computers and other plug-in equipment (which generate heat) are not included in this calculation, heating amounts to 15 - 40% of the energy cost. Efficient heating systems save significant energy.

- **Reduced Emissions**
  Lower energy use results in lower emissions of CO₂, NOₓ, and SOₓ. The air quality improves significantly by completely replacing coal as fuel, and by using natural gas in preference to oil. Oil with higher number designation (e.g., 6) pollutes less than oil with lower number designation (e.g., 2).

  While there are no local, onsite emissions when heating with electricity, emissions do occur at the site of electricity production (not only is electricity production generally inefficient, plant site selection often raises environmental justice issues).

- **Resource Conservation**
  Use materials with recycled content for insulation. The steel in the HVAC system already has at least 20% recycled content.

- **Noise**
  Steam system operation in older buildings is often noisy. System repairs or replacement will correct this situation.
Benefits (cont’d)

- Indoor Air Quality
  Fuels that result in lower emissions will likely result in better indoor air quality, especially in buildings that use natural ventilation (i.e., unfiltered outside air).

Boiler leaks, leaky pipes, and condensate pans for heat pumps can create mold problems.

Life-Cycle Assessment

A simple payback calculation may suffice to select between alternative heating systems (or components) that have different first-costs and energy costs. If the payback of a more efficient system is clearly attractive (e.g., three to five years), that system should be implemented. If the payback is exceedingly long, approaching the life of the component (e.g., 15 years for a control component such as oxygen trim), the system will most likely be excluded from further consideration. For results in-between, a life-cycle cost (LCC) analysis is recommended.

LCC analyses are always useful for selecting among mechanical systems, or mechanical components, that differ significantly in maintenance, repair, or replacement costs. For example: cast-iron boilers are “work horses,” often serving reliably for 40 or 50 years or more, even with minimal maintenance. Steel boilers have shorter lives (perhaps 20 to 25 years) and require more frequent repairs, but have much lower first-costs. In addition, the only current choice for condensing boilers is the steel option. Only an LCC analysis can properly indicate which boiler type is most cost-effective.

When comparing a steel and a cast-iron boiler, the energy calculation can be very simple. However, if a geothermal heat pump system or a cogeneration system is considered, perform a computerized energy simulation.

Leaky flues can result in carbon monoxide poisoning. Unintentional air pathways between the boiler room and occupied areas spread soot and odors. Periodic maintenance of these subsystems pays off in better IAQ.

Additional Information

Key Words for Internet Searches
AFUE, thermal efficiency, modular boilers, condensing boilers, heat recovery

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High-Performance Renovation: Cooling and Ventilation Systems

The Role of Cooling and Ventilation Systems

Many older public buildings have mechanical systems with components (whether original or not) that are in need of serious repair or replacement. Replacement brings not only increased reliability and comfort, but also lower energy costs. Further, ozone-depleting CFC refrigerants in existing cooling equipment can be replaced with HCFCs (which will be phased out between 2020-2030) or with HFCs.

Timing / Staging

Some renovation projects involve the introduction of a new mechanical cooling system. To do this properly, first assess the potential for reducing the need for cooling (and in the process also consider heating). Upgrade the windows, install more efficient lighting, and use more efficient equipment -- such as ENERGY STAR computers, printers, refrigerators, etc. In buildings with compromised roof insulation, install code-compliant insulation (insulation levels above code reduce heating loads, but are not effective in decreasing cooling loads).

System Integration

_Fenestration, lighting and plug equipment_

The size, and sometimes the type of cooling system is strongly influenced by the magnitude and profile of the cooling load. Chillers and air-conditioners are manufactured in specific sizes; therefore, a small reduction in cooling load may not be sufficient to downsize. Typically, the decrease in chiller size, and even more so, the decrease in pipe and fan size, is triggered by the combined effect of better windows (lower solar gain) and of low-density lighting. If an assumption can be made that the plug loads will be smaller than before, the downsizing will be even greater ($I$) (newer computers and monitors release much less heat than models from just five years ago -- and the trend continues).

If the cooling load decreases sufficiently, even the type of cooling system could change. Cooling loads above 200 tons are often met with centrifugal chillers, but below that threshold other chiller types usually are more cost-effective (e.g., screw).

**Terminology**

- **CAV:** Constant Air Volume.
- **Chiller:** Device that chills water to provide space cooling.
- **CFC:** Chlorofluorocarbon. Type of refrigerant that causes damage to the earth’s ozone layer and has significant global warming potential (no longer manufactured in the U.S.).
- **Condenser:** Component through which a chiller rejects heat. In a typical cycle, the condenser inside the chiller condenses – passes from vapor to liquid form – and releases heat.
- **COP:** Coefficient of Performance. For absorption chillers, COP is the ratio of heat extracted (that is, of cooling performed) to the heat used to perform the absorption cycle. Higher COP means greater efficiency.
- **DX:** Direct expansion. Refrigeration cycle that cools air by blowing it with refrigerant (the evaporator).
- **DX Unit:** Device that uses the DX cycle to cool air. It has an evaporator (where it cools air), a condenser (where it rejects heat), a compressor (that actsuates the DX cycle), and auxiliary equipment. A DX unit cools air directly, while a chiller first cools water, which in turn is used to cool air.
- **EER:** Energy Efficiency Ratio. Indicator of the energy efficiency of an air conditioner at rated conditions, expressed by the ratio between BTU of heat extracted and the electricity used to obtain this cooling effect.
- **Evaporator:** Component through which a chiller absorbs heat from air or water by allowing a refrigerant to evaporate within a coil.
- **HCFC:** Hydrochlorofluorocarbon. Refrigerant that is less damaging to the ozone layer than CFC (being phased out).
- **HFC:** Hydrofluorocarbon. Refrigerant that does not damage the ozone layer.
- **Latent load:** Cooling load produced by processes that increase the humidity in a space above desired limits, such as humid summer air, moisture released by cooking, or moisture from people in a space.
- **NEMA:** National Electrical Manufacturers Association provides a forum for the standardization of electrical equipment.
- **Refrigerant:** Substance essential to a chiller or DX unit that absorbs and rejects heat.
- **SEER:** Seasonal Energy Efficiency Ratio. Indicator of the energy efficiency of an air conditioner, similar to the EER, only that it includes the results of tests that attempt to approximate the operation of the equipment at different conditions.
- **Sensible load:** Cooling load produced by processes that increase the air temperature in a space above desired limits, such as solar radiation or heat emitted by lights.
- **Ton of Cooling:** Heat absorbed every hour by a ton of ice that melts during 24hrs (12,000 BTU/hr).
Variation in cooling loads may be met with VSD chillers for buildings with peak loads above 200 tons, but below 200 tons it may be more advantageous to use multiple chillers or multiple-compressor chillers.

Site work for sports fields and parking lots offer the opportunity to lay horizontal geothermal piping. See Guide 7: Heating System Upgrades.

The Role of Cooling and Ventilation Systems (cont’d)

1. Remedy IAQ deficiencies created by the cooling system. These may include, among others,
   - Outside air intakes that entrain fumes, pathogens, odors;
   - Dirty cooling coils, filters, ducts, and ceiling plenums used as return air pathways;
   - Low temperature ducts with insufficient or damaged insulation;
   - Condensate pans that do not drain properly;
   - Cooling systems that are so oversized that they cycle off before performing dehumidification.

2. Repair or replace cooling systems that damage other building systems. If the sleeves of through-the-wall air conditioners are not properly pitched, rain water could find its way into the wall. Rooftop equipment could have damaged the roofing membrane, allowing water to seep into the insulation layer. A chiller or large DX unit that vibrates could damage the structure.

3. Ensure that the AV system delivers sufficient outside air at any setting of the VAV boxes. Control the outside air damper to deliver the minimum design outside air (OA) rate, regardless of the total volume of air. An exception is if CO₂ sensors modulate the outside air rate.

4. Ensure that the air system is properly balanced. Check for fire dampers that obstruct ducts, mispositioned flow diverters, and unbalanced CAV or VAV boxes.

5. Consider refrigerant replacements. Serviceable cooling equipment that employs CFC refrigerants could be converted to HFC refrigerants. The replacement refrigerants will diminish the cooling capacity by 10-15%. In most cases this will not be a problem because cooling systems tend to be oversized. In addition, the cooling load may have already been reduced by retrofits.

6. Eliminate summer overheating. First, assess whether the cooling system operates properly. Next, examine whether reductions in cooling load are sufficient to restore comfort. For example, you can install more efficient lighting and shade the windows. Finally, add cooling capacity. This could mean additional chillers, but also consider reducing the supply air temperature. Ice storage alleviates a capacity shortfall while also offering operational economies during periods of lower-cost electricity (ensure that the existing chillers are suited for the low-temperature application).

Also, for systems with large amounts of outside air, consider an enthalpy wheel.

7. Consider upgrading components for energy efficiency, if a cooling system is in good condition and has significant useful life left (e.g., more than five years).

8. Consider replacing old cooling systems, or cooling systems necessitating major repairs, with new energy-efficient systems.
   - Convert CAV systems to VAV (see discussion below);
   - Replace the chiller plant with higher efficiency equipment. Do not oversize. The existing chiller plant may already be too large if other improvements have taken place.

Cooling and Ventilation Strategies

Cooling is performed with DX units and chillers (see terminology).

DX units that serve commercial buildings range from less than 1/2 ton to hundreds of tons in cooling capacity. They can be packaged—like the rooftop units or room air conditioners (2), or split—like the water-cooled DX where the condenser water is sent to a remote cooling tower. DX units are inexpensive to install and to maintain, but are relatively inefficient.
Cooling and Ventilation Strategies

Chillers use electricity, steam, or natural gas to cool water. They perform more efficiently when they produce water at higher temperatures (e.g., from 44°F, where they are rated, to 48°F - 50°F).

There are some situations in which low water temperature (e.g., in the 38°F - 42°F range) may be desirable, including: 1) buildings with very high cooling loads, and 2) retrofit situations where the existing ducts are small (perhaps because the cooling loads of the new use are much higher than those for which the ducts were originally sized, or because ducts previously used for heating now are employed for cooling). A 10% decrease in water temperature could result in a 10-15% decrease in chiller efficiency. The pumps and fans work less, however, for the same pipe and duct sizes, so the overall energy use may be the same or even lower.

Always insulate the chilled water pipes and the low temperature ducts, to avoid moisture condensation.

For larger buildings, the Energy Office recommends and has been working with the Capital Program Office to install hybrid chiller systems. These systems include chillers with different energy inputs, generally gas and electricity. This allows the City to base-load the unit with the lowest operating cost. In recent applications, the gas chillers have been driven by natural gas-fired engines where the coolant is circulated through a heat exchanger to produce domestic hot water.

Install Efficient Air-Cooled Chillers and DX Units ($$$-$$$$)

When the outside air is cold, these chillers and DX units are reasonably efficient and appropriate for winter operation. In summer, however, the hot air does not cool well and the efficiency of this type of equipment is low - about 1.1-1.3 kw/ton (or EER of about 9-11). Air-cooled equipment is usually small, below 200 tons. Room air-conditioners can be smaller than 1/2 ton.

Improve the efficiency of chillers or DX units by selecting ones with the smallest kw/ton rating (or the highest EER) and condenser fans that have several speeds or variable-speed drives.

Install Efficient Water-Cooled Chillers and DX Units ($$$-$$$$$)

These units range from less than 5 tons to thousands of tons. They reject heat to water, and that water, called condenser water, is transported to a place where it is cooled in turn. Water-cooled equipment is more complex and costs more than air-cooled equipment, but it is more energy efficient.

Cooling towers (3) cool water mainly through evaporation. They use pumps to bring the water from the chillers, and fans to blow air over that water. A DX unit cooled with cooling towers could have an EER of 12-14 (or about 0.7-0.85 Kw/ton), which is 20-30% better than that of an air-cooled DX. Usage of chemically-treated water is quite high. One additional disadvantage is that cooling towers release a plume of moist air, visible during cool days.

- Do not undersize cooling towers, as they are about 10 times more energy efficient than chillers. Wherever possible, provide 3 gpm/ton of condenser water. Use cooling towers to provide cooling during winter, bypassing the chillers.
- Specify NEMA premium efficiency motors for the fans and pumps of the cooling towers.
- Fans should be two-speed, and preferably variable speed. Variable-speed pumping of condenser water could increase chiller energy use more than it decreases tower energy use. To ensure savings, use this strategy as part of an optimization control package for the entire chiller plant.

Closed loop river/lake cooling system (4) - used condenser water is circulated through coils submerged in a nearby river or a large lake. A DX unit could reach an EER of 18-20. However, permitting must be secured and the connection to the river could be costly. For best results use premium efficiency motors and VSD pumps. Operate the pumps only when there is a load. Bypass the chiller or DX unit when the water temperature is sufficiently low to meet the load.

Closed loop ground cooling - condenser water is circulated through pipes located in the ground, in vertical wells that are usually 150-500 feet deep, or in horizontal trenches, usually at least 8 feet below ground surface. Ground cooling is more energy-efficient than a cooling tower (e.g. EER of 14-15 for a DX unit), but is very costly. Consider about 180 linear feet of well per ton of cooling, at an installed price of $15-30/lf (including tubing). However, do not undersize the ground loop. Short loops return water at high temperature back to the DX unit or chiller, degrading their performance to that obtained with a cooling tower.
Pumps must have premium efficiency motors and variable-speed drives, and should operate only when the building requires heating or cooling.

When possible, use loop water to cool without activating the compressors. This saves energy.

Standing column well systems cool the condenser water in wells that are 1,000 to 1,500-feet deep. The pump is located at the bottom of the well. The system requires about 60 linear feet of well/ton, at a cost that could be in the range of $25-$40/lf. The efficiency of this system is greater than that of the closed loop system (a DX unit could get EER of 16-18), and even approaches that of the open loop system if a heat exchanger is not required. However, the pumping energy use could be too high if water is far from the surface (e.g., over 50 ft.)

Use premium efficiency motors and variable-speed drives for pumps, if feasible, to significantly reduce the energy cost. Do not operate the well pump unless required by a building load.

Bypass compressors with ground water for off-peak periods of operation.

Where necessary, select a high-efficiency heat exchanger between the building loop and the well water.

Open loop systems allow the chillers to be cooled directly by ground water extracted from a well, or by water from a river or lake. This water is run over the condenser, and injected into another well (or returned to the river or lake) -- the most energy-efficient type of geothermal cooling. Without a heat exchanger, the EER for a DX unit could be in the range of 18-20. The ground water should not be too far from the surface (e.g., 50 ft.) otherwise pumping energy will be too high. The water flow has to be 2 gpm and preferably 3 gpm per ton of cooling. The cost per well could be in the range of $15,000 to $50,000. There may be a need for frequent maintenance of the heat exchanger. Use the same energy efficiency strategies as in standing column wells.

Install Efficient Electric Chillers ($$-$$$$)

Centrifugal chiller size starts at about 200 tons. Below 300 tons these chillers command a premium. Centrifugal chillers are usually water-cooled. For single-speed chillers the efficiency typically ranges from 0.51-0.62 kW/ton at peak load – but usually these chillers operate most efficiently at 70-80% of load. At low loads the efficiency decreases quickly. Centrifugal chillers with variable-speed drives (VSD) are about 10% less efficient than regular (single-speed) centrifugal chillers at peak load, but because of superior performance at part load, especially in the 40-70% range, VSD chillers cost less to operate.

Screw chillers are powered by electricity, range in size from about 40 to 500 tons and, when water-cooled, are usually rated at 0.60-0.70kw/ton. Air-cooled chillers are less efficient. Some water-cooled screw chillers have very good part-load efficiencies and approach the electricity use of centrifugal chillers at a lower first cost.

For the renovation of electric central plants in the 200-500 ton range, compare screw chillers with centrifugal chillers. Computer modeling will yield more accurate results than spreadsheet calculations.

Refrigerating chillers range in size from about 10 to 200 tons, and, when water-cooled, have efficiencies that are typically in the range of 0.70-0.85kw/ton. Air-cooled refrigerating chillers are commonly rated at 1.1 to 1.3 kw/ton.

The modular refrigerating chillers are often designated as multi-stack chillers. The efficiency of refrigerating chillers is mediocre, but in a modular setup they can match the load quite well and be at less of a disadvantage when compared to screw chillers. Because of their small size, they can also be more easily installed in existing buildings. This feature can be advantageous for historic structures where it is very costly to open the façade in order to accommodate larger chillers.

Scroll compressor chillers range from about 20-100 tons. They are similar in efficiency and application with refrigerating chillers, but have fewer moving parts and therefore lower maintenance.

For the renovation of electric central plants in the 20-200 ton range, compare screw and scroll chillers with refrigerating chillers. Computer modeling will yield more accurate results than spreadsheet calculations.
Cooling and Ventilation Strategies (cont’d)

Install Efficient Absorption Chillers and Chiller/Heaters ($$$$) (8)
Absorption machines use heat to sustain a chemical and physical process that results in chilled water. Most often the heat is produced by burning natural gas (gas-fired chillers) or is extracted from steam (steam chillers). Sometimes the absorption process uses waste heat generated by some industrial process (waste heat chillers).

The efficiency of absorption chillers is expressed as the coefficient of performance (COP), like boilers or heat pumps. If the process is performed in one stage, the cycle is called single-effect. Single-effect chillers have a COP of about 0.5. Double-effect chillers, which use two stages in the process of chilling water, have a COP of about 1.0. Because of their relatively low efficiency, single-effect chillers are used only in special situations:

- Where the cooling load is very small, perhaps below 50 tons, because double-effect chillers are not available (these small chillers are air-cooled);
- Where the heat source is low-pressure steam or low temperature waste heat that cannot sustain the double-effect cycle.

The heat rejected from the cooling process can be directed to satisfy, partially or totally, the heating needs. For instance, simultaneous cooling and heating is required in buildings with large core areas that need year-round cooling, or in buildings where the air is cooled at low temperature for dehumidification purposes, and then needs to be reheated. In such situations the absorption chiller with heat recovery saves reheat energy. (The heat is recovered by placing a heat exchanger on the condenser loop.)

An absorption chiller that has a heating module is a chiller/heater. If only heating is required, the heating module operates like a boiler with approx 80% efficiency. If the building requires both heating and cooling, the heat generated by the burners is allocated to both chiller and heating module. This increases the overall operating efficiency.

Absorption chillers incur small electricity demand charges by comparison with electric chillers. For this reason, and depending on the cost of natural gas (or steam, or waste heat), absorption chillers may reduce facility energy costs. But absorption chillers can cost 50-100% more than electric chillers, and the cooling tower for absorption chillers is about 50% larger than that for electric chillers.

The maintenance of absorption chillers should be similar to that of electric chillers, as long as the monitoring of chiller functions is automated.

Perform energy modeling to compare electric and absorption chillers. Account for distribution losses of steam and waste chillers. If absorption chillers are selected for a project, investigate whether an oxygen trim system is feasible. This system ensures that the combustion process always uses the optimum amount of oxygen, and can boost system efficiency by 2-5%. The installed cost for this system is in the $10,000 to $30,000 range.

Other Chillers ($$$$)
Large buildings sometimes use steam-driven turbine chillers and engine-driven chillers. They can be more cost-effective than the other chiller types, but are uncommon in retrofit situations because they are larger and more expensive.

Install VAV and CAV Systems ($$$-$$$$)
Traditional variable air volume (VAV) systems operate at constant air temperature and modulate the air flow with a VAV box to provide a comfortable temperature within a space. For good air mixing, the VAV box usually does not close below 30-40% of its maximum capacity, even when the cooling load is small and ventilation air would be satisfied at a much smaller fraction of capacity (e.g., 10%). A fan-powered VAV box has a small fan that recirculates the air in the zone, for proper mixing. The primary air, coming from the main airhandler, can be throttled down as low as permitted by ventilation needs.

- Provide variable speed drive for the VAV fan. Inlet vanes are less efficient and require higher maintenance. (see Guide #9: HVAC Controls & Automation for reheat minimization strategies using direct digital control at VAV boxes).
- Fan-powered VAV boxes should be used for spaces that have large variations in cooling loads, such as conference rooms or multipurpose assembly spaces. Fan-powered boxes are also useful in low-temperature air systems, where they mix the very cold primary air with air from the room. This strategy reduces the amount of reheat and is especially effective when the central fan serves both perimeter and core areas. In this situation, the perimeter will, at times, have higher solar gains and require colder air; this colder air, in turn, may need to be reheated in core zones. Alternately, during cool and cloudy weather,
Cooling and Ventilation Strategies (cont’d)

- A call for cooling from core spaces may result in a need for reheat in perimeter spaces. Fan-powered VAV boxes reduce the need for reheat. For greatest reductions, consider a core space location for the fan-powered VAV boxes that serve perimeter spaces.
- Use efficient, electronically-commutated motors (ECM) for fan-powered VAV boxes. Without ECM, fan-powered boxes may only minimally reduce the total fan energy cost.

**Constant air volume (CAV)** systems maintain the same air flow at all times, but continuously vary the temperature. While they achieve very good air mixing, CAV systems are more energy-intensive than VAV systems.

**Conversion of CAV to VAV systems is recommended in the following situations:**

- **When fans are oversized even for peak load**, which occur only a few days a year. For the remaining time, the air system operates at a fraction of its capacity. A VAV system (in part or in full) with a variable speed drive saves energy in comparison to a CAV system, even if the VAV fan throttles only to 70%-80% of capacity.

- **In high occupancy spaces**, such as cafeterias and libraries, where the air must be mixed well and dehumidified. At peak occupancy the VAV box can be fully open. At other times, these spaces often have much lower occupancies and the VAV box can throttle down to 70%-80%. In most cases, this air flow will satisfy off-peak mixing conditions.

- **When existing CAV boxes need replacement or repairs.** Typical VAV boxes cost about the same as CAV boxes.

Use **Underfloor Air Delivery Systems ($$$-$$$$)** (9,10) These systems are also known as **displacement ventilation systems**. Cool air is brought under the floor and distributed through diffusers in the floor. The diffusers can be manually controlled (the occupant opens them as much as desired), or can act as mini-VAV boxes. Sometimes the underfloor area is partitioned into sections, some of which are served by full-size VAV boxes; the occupants perform further adjustments with the manual diffusers. In general, cool air delivered at floor level has two advantages:

- The air conditions only the occupied zone of the room – an issue in older buildings with tall ceilings.
- The air is much warmer in temperature than air distributed overhead – about 60º - 65º F compared to 50º - 55º F typical of overhead air. As a result, the OA economizer range increases, reheat needs are reduced, and the chillers operate more efficiently. The need for dehumidification, however, may at times preclude this operation strategy.

On the minus side, these systems often (but not always) have higher fan energy.

A detailed discussion of these systems cannot be accommodated here. Overall, they can reduce energy use, especially when the same fan serves both perimeter and core areas. Occupants are usually pleased by the level of control over local temperature.

The drawbacks are first-cost, and the need to have at least 8 inches (preferably 12 inches) underfloor space. But the latter requirement is not restrictive if the hung ceiling can be eliminated (acoustic panels can be mounted against the underslab of the ceiling, and/or hung in strategic locations).

**Use Heat Recovery Devices for Cooling Systems ($$$-$$$$)**

- **Enthalpy wheels** (11) dry and precool the intake air by contact (through a desiccant medium) with the exhaust air. Outside air is forced through half the wheel. That portion of the wheel is relatively cool and dry, so the outside air loses some of its heat and humidity before being introduced into the building.

The wheel turns and the exhaust air cools and dries that portion of the wheel. The cycle repeats. Enthalpy wheels reduce cooling costs and can decrease the chiller size. They also reduce heating costs. Fan electricity use increases, but for systems with high outside air ratios the enthalpy wheels can have an attractive payback. The disadvantages include entrainment of pollutants from exhaust air into the outside air supply, first cost and additional maintenance. To reduce or eliminate entrainment problems specify an enthalpy wheel with very small cell size.

**Indirect evaporative coolers (IDEC)** spray water on the exhaust air, which cools by evaporation (12). This cooled exhaust air absorbs heat from the intake air through the walls of a heat exchanger. IDEC devices reduce cooling energy use much more than the relatively small increase in fan electricity
Cooling and Ventilation Strategies (cont’d)

use due to the heat exchanger. The drawbacks are first-cost, water use, and additional maintenance.

Electric chillers with heat recovery (also called double-bundle chillers) can be useful for buildings with simultaneous heating and cooling. Since the chiller efficiency decreases, these devices are usually cost-effective if the rate for electricity is relatively low, and the rate for heating (gas, oil) is relatively high.

Use Efficient Fan-Coil Units ($$-$$$)
Variable speed pumps that serve fan-coil units save energy, and programmable, wall-mounted thermostats offer significant energy savings and better temperature control compared to return air sensors.

Use Efficient Water Loop Heat Pump Systems ($$-$$$)
Heat pump systems are reversible DX devices that can extract heat from spaces and reject it to a water loop. They also take heat from the water loop and deliver it to other spaces. As a result, they operate efficiently in buildings with simultaneous heating and cooling loads. If most of the building load is cooling, the heat accumulating in the water loop is rejected to a cooling tower, to the ground, or to a body of water. The last two cases are geothermal heat pump systems.

If the building requires mostly heating, heat is provided to the water loop by a boiler (or steam, or waste heat from industrial processes), or, in the case of geothermal heat pumps, from the ground or the body of water.

The advantage of heat pumps is low first-cost and versatility. Geothermal heat pumps are also very energy efficient in cooling (but not more efficient than screw or centrifugal chillers that reject heat to the ground). In heating, geothermal heat pumps could cost as much or more to operate when compared with a condensing boiler system, but may reduce costs when compared with a typical, 80% efficiency boiler.

Other factors to consider with heat pumps include: 1) an air economizer is not feasible because outside air is introduced by a separate air system; 2) there are fewer options to increase the energy efficiency beyond a base design compared to a chiller plant; 3) some level of local noise is generated if installed as a distributed system next to the zones they serve; 4) regular cleaning of condensate pans is required; and 5) compressors will begin to fail after approximately 15 years.

Perform computer energy analyses to calculate and compare the energy cost of a building with a heat pump system versus a central chiller system.

Use Efficient Packaged DX Units ($-$$)

Some buildings are served by rooftop DX units. These units are fairly inefficient because of limitations inherent in air-cooled equipment, and because, through their position outside, they are prone to air leaks. However, there are ways to improve DX performance:

- Specify the most efficient DX unit – but ensure that the latent capacity is appropriate for the project. DX units are typically available in EERs that range from 9 to 12.
- Use VAV DX with variable-speed drive (units of 15 tons or larger).
- Use cycling or multi-speed fan, if available, for the condenser side.
- Use premium efficiency motor for the fan.
- Air-seal the DX unit.
- Provide maintenance access paths to protect the roofing membrane.

Some buildings are still served by through-the-wall or window air conditioners. Window AC units are about 10-20% more energy efficient because they reject heat through a larger surface area. However, they block light and views, and are unsightly. Select units with high SEER. Ensure that the air-conditioner sleeves (for through-the-wall units) are properly sealed and tilted outside to avoid water damage to the wall.

ENVIRONMENTAL ISSUES

Use Environmental Refrigerants
When existing chillers need additional CFC refrigerant, replace this refrigerant with one that is more benign. HCFC refrigerants are energy-efficient, have small global warming potential, but still deplete the ozone layer – even though to a small extent. R123, mostly used in large chillers, will not be produced after 2030. R-22, mostly used in reciprocating chillers and DX units, will be phased out by 2020.

HFC refrigerants (e.g., R134a) do not deplete the ozone layer but have higher global-warming potential than the HCFC class. The best R-134a chillers are currently about 10-15% less efficient than the best R-123 chillers.
**Benefits**

- **Comfort**
  Cooling systems that are not oversized dehumidify better.

- **Energy Savings**
  An efficient cooling system saves energy. Proper zoning of HVAC distribution results in less need for reheat and can minimize operating hours to address overcooling.

- **Reduced Emissions**
  Lower energy use results in fewer emissions of CO₂, NOₓ, and SO₂.

- **Resource Conservation**
  Use materials with recycled content for insulation. The steel in the HVAC system already has at least 20% recycled content.

Absorption chillers use water and lithium-bromide. Neither depletes the ozone layer or has a global-warming effect.

Specify Duct Liners with Good IAQ Features

Most acoustic duct liners are manufactured with glass fiber; some are now available with natural fibers. Consider protecting these liners with perforated metal sheet to reduce the release of fibers into the air stream.

Reduce Construction Waste

Steel used for chillers and for sheet metal has at least 20% recycled content. Insulation for piping and low-temperature air can have recycled content of 5% - 80%.

Life-Cycle Assessment

Life-cycle cost analyses are essential for selecting between different cooling systems, such as heat pumps, electric chillers, absorption chillers or engine-driven chillers.

Whenever possible, perform a computer-based energy analysis. The energy cost depends greatly on the interplay between electricity and fuel rates (and how these rates vary over time), on the variation in cooling loads, and on the efficiency of the equipment at different part-load ratios.

Use the *ASHRAE Equipment Handbook* to obtain estimated life spans for various equipment types.

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**High-Performance Renovation: HVAC Controls & Automation**

**Philadelphia High-Performance Building Renovation Guidelines**

**The Role of HVAC Controls & Automation**

Like car automation, HVAC automation is part of everyday life, performing tasks that are impractical or impossible to perform manually. Obviously, not all controls are appropriate for all buildings – but certain controls should be included in every renovation if they are not already in the building.

Simple controls include time clocks, programmable thermostats (1), or variable speed drives. More complex computer-based controls employ a Building Automation System, also known as a Building Management System, to monitor dozens or hundreds of "points" throughout a facility to optimize performance. A Building Automation System supervises a number of functions, including the energy use (through a subset usually identified as the Energy Management System – (EMS) (2)), fire, security, transportation and others.

**Timing / Staging**

HVAC controls need to be discussed early in a major renovation project if operable windows are considered (will the HVAC turn off when windows open?) and/or if the energy efficiency goals are ambitious. The latter case usually requires DDC controls.

Otherwise, ensure that HVAC controls are coordinated with lighting and IAQ controls, and with the other control functions of the building – mainly fire, smoke, and security.

**System Integration**

Operable windows have significant psychological benefits and can improve indoor air quality. They also affect the energy use – favorably or unfavorably. Some designers and building managers oppose operable windows because these windows can be kept open while the building is mechanically heated or cooled; this increases the energy use and destabilizes the pressurization of the building. However, the HVAC system can be connected with a contactor located in each window frame. When the window opens, the contactor automatically shuts off the HVAC.

**Lighting**

Some control functions can be shared by lighting and HVAC. For instance, occupancy sensors can be used to turn off lights and to decrease the temperature in a room.

**Indoor Air Quality**

IAQ and HVAC can share monitoring functions. For example, an outside air temperature sensor can be used to determine the need for humidification (an IAQ issue) and to adjust the hot water temperature for boilers.

**Terminology**

- **Analog control**: A control technique that uses mechanical devices, such as compressed air.
- **DDC**: Direct digital control: A control technique that uses electronic devices.
- **Dry bulb temperature**: Temperature read with a regular thermometer.
- **Energy Monitoring**: Activity through which a central system tracks how temperature, air flow, water flow, electricity and other physical variables of an energy-using building system change over time.
- **Enthalpy of air**: Total heat contained in air, including sensible heat (that we perceive as temperature) and latent heat (that we perceive as humidity).
- **Humidity**: Device that records data such as temperature, air flow, etc.
- **Monitoring Point**: Device that transmits the data recorded by a meter to the central system.
- **Thermal zone**: A building zone that experiences very similar heating and cooling needs in all its areas. For example, a row of offices facing the same direction.
- **Corner offices** belong in a separate thermal zone because they have windows facing in two directions.
- **Variable Speed Drives (VSD)**: Drives controlled by an electronic device which varies their speed according to demand. In buildings, VSDs are used for motors that actuate fans, pumps, chillers, and sometimes elevators.
- **VAV**: Variable air volume.
- **VOC**: Volatile organic compounds. In buildings, these are chemicals emitted by some materials such as paints, adhesives and sealants. These chemicals can irritate the lungs, aggravate asthma, and trigger allergic reactions. Some commercially available products have lower VOC content than others.
- **Wet bulb temperature**: Temperature read with a thermometer that has the bulb wrapped in a wet wick. Because the water on the wick evaporates, it cools the thermometer. Thus, the wet bulb temperature is lower than or equal to (at 100% humidity) the dry bulb temperature.
The Role of HVAC Controls & Building Automation (cont’d)

Energy
Many energy-saving control strategies can share hardware and thus economize equipment costs. For instance, an outside air temperature sensor can be used to reset the temperature of hot water and to activate the optimum pump start.

Scale of Importance
1. Controls that affect safety are the first priority. Example: High-pressure shutoff for boilers.
2. Controls that are simple to understand and operate, are low cost, and that require minimal maintenance are the second priority. See "Life-Cycle Assessment."
3. Controls with attractive economic return are the next priority. Some of these controls are more complex, or can only be implemented in the context of a full-blown DDC system. Others are expensive. An economic analysis should be performed to determine their effectiveness. See "Life-Cycle Assessment."

Control Strategies
This section presents information useful for selecting some typical controls.

Avoid using energy-wasting temperature controls. Examples include:
- radiator valves as the only temperature control,
- reset of hot water temperature based on outside air temperature as the sole means to adjust space temperatures, or
- a single thermostat controlling more than one thermal zone, such as a perimeter and a core.

Space limitations preclude a discussion of all possible control strategies. Costs for controls, and for their installation, vary depending on the type of installation (off-the-shelf or customized), magnitude of the job, type of labor required, site conditions, and other considerations. Check with local contractors to obtain reliable cost estimates.

To serve effectively, controls need regular calibration. Failed sensors and false readings can waste considerable energy.

Programmable Thermostats for Each Thermal Zone ($-$-$)
A programmable thermostat should be installed in each thermal zone. Such thermostats can be self-contained, or connected to the EMS.

Outside Air Temperature Sensor (3) to Reset the Temperature of Heating Hot Water ($)
This is a low-cost, effective method to reduce heating energy use. As the outside air temperature increases, the boilers produce water that is less hot. As a result, the boilers lose less energy by cycling on-off (as noted above, this should not be the sole means to adjust the space temperature).

Reset the Temperature of Heating Hot Water Based on Return Water Temperature ($)
This strategy can be used in conjunction with, or instead of, the one just above. If the return water is too warm, the boiler is directed to heat less of the supply water. The reason for this is that when the hot water control reset is based on outdoor air temperature (see above), it cannot account for variations in solar loads or internal loads. For example, a south-facing space could need a higher water temperature when it is 50º F and cloudy outside, but a lower water temperature when the sun is streaming through the windows.

Optimum Fan Start/Stop for Fans and Pumps ($)
In many buildings, the heating system is turned on hours before occupancy, even though this is necessary only for very cold days. An optimum start control activates the hot water pumps (or fans, if heating is performed with hot air) based on outdoor air temperature – sooner during cold spells, later otherwise.

It is also possible to initiate the setback mode before the end of the occupancy period based on outside air temperature. This strategy can be utilized because temperature decreases gradually, especially in massive buildings, after the heating system has switched to setback mode. Occupant comfortable will remain constant through the end of normal occupancy hours.

Outside Air Damper Controls for Warm-Up Cycle ($-$-$) (4)
Some hot-air heating systems bring in outside air whenever the fans operate. This is wasteful. During periods without occupancy, and also during the period of recovery from setback (also know as the warm-up cycle), controls should shut the outside air damper.

Variable Speed Drives (5) for Fans and Pumps ($-$-$)
Typically, heating hot water systems benefit from variable speed pumps that throttle down to about 30%. These pumps use much less electricity than those with constant speed. Primary/secondary chilled water systems also benefit from variable...
Control Strategies (cont'd)

For chilled water systems with a primary circuit only, or for the primary circuit of a primary/secondary system, some engineers prefer to use constant speed pumps. However, the chilled water flow can vary to some extent without affecting chiller operation. Typically, the flow can decrease to 70%, and sometimes even lower, without any problem. In variable speed pump operation, most savings are actually achieved between 100% and 70% operation.

Fans in VAV systems should always have VSDs, whether they throttle down to 30% (in offices) or only to 70% (as may be the case in a conference space).

Even constant-volume air systems can benefit from VSDs. Since all fans are oversized, it is almost certain that even a constant volume fan can be adjusted to operate at less than capacity, using a VSD. The energy savings are the greatest between 100% and 90% of capacity.

Fans for cooling towers always benefit from two-speed control. Variable speed control is sometimes cost-effective, especially if the towers are significantly oversized.

Wet Bulb Reset for Cooling Tower ($)

Cooling towers are often controlled to send water at 85°F (or a similar temperature) to the chillers at all times. With wet bulb reset control, the tower fans work as hard as possible to send the lowest water temperature to the chillers. Chillers become more efficient when cooled with low temperature water. The increase in chiller efficiency saves much more energy than what is expended to run the tower fans harder.

There is a limit on how cool the water can be. First, since the towers cool the water primarily through evaporation, if the outside air is humid (i.e., the wet bulb temperature is close to the dry bulb temperature), the water will be cooled less. Second, most chillers can not receive water that is cooler than 60°F to 70°F. Even with these limitations, the wet bulb reset control is highly effective in Philadelphia.

Economizer Control ($)

Outside air economizers with dry bulb control provide 100% outside air to a space when the outside air temperature is below a pre-set level (e.g., 65°F). The control allows outside air to be introduced while the chillers function, as long as the enthalpy of the outside air is lower than that of return air. Once the cooling load can no longer be met by 100% outside air, the outside air damper moves to the minimum position and the chillers provide all cooling.

A more energy-efficient control strategy equips the economizer with two enthalpy sensors: one for outside air, and one for return air. As long as the outside air has even slightly lower enthalpy than the return air, it makes more sense to run the chillers with 100% outside air, instead of returning any air back from the conditioned spaces.

Minimization of Reheat in VAV Systems Using Direct Digital Controls (DDC) ($$$)

In basic VAV systems, the air supply rate changes to accommodate cooling or heating needs. This air is delivered at constant temperature, and reset seasonally -- lower in summer, higher in spring and fall. During cool weather, even with the VAV boxes (6) at minimum position, the air temperature could still be too cold; most spaces are over-cooled. Reheat coils maintain comfort in such situations, at an energy cost.

In VAV systems where the VAV boxes are equipped with DDC, the control system senses whether (a) a VAV box is at minimum position and whether (b) the space temperature is nonetheless too cold or (in reheat systems) whether the reheat coil is activated. If these two conditions are met, the temperature can be increased until the overcooling (or reheat) disappears. The control strategy can be as simple as described above, or can involve optimization routines.

Oxygen Trim for Boilers and Gas-Fired Chillers ($$-$$$)

Oil and gas boilers and gas-fired chillers burn fuel to produce heat. The combustion process is most efficient when the oxygen is supplied within certain bounds. An oxygen trim control package maintains the oxygen within these bounds, saving 2% to 5% in fuel use per year. This control strategy, which is applicable to both oil and gas boilers, is usually cost-effective for non-condensing boilers only.

Use Environmental Materials ($$-$$$)

Most metal used for HVAC controls has recycled content: very high for copper and aluminum, at least 25% for steel.

Reduce Construction Waste ($-$)

All metal from demolition can be recycled to reduce construction waste.
Benefits

- **Comfort**
  Some controls increase comfort while saving energy. Examples: programmable thermostats and DDC control of VAV boxes.

- **Energy Savings**
  HVAC controls are highly effective in saving energy.

- **Reduced Emissions**
  Lower energy use results in fewer emissions of CO₂, NOx, and SOx.

- **Indoor Air Quality**
  Some HVAC controls can increase the air quality – e.g., controls that maintain the CO₂ or VOC content within certain limits.

Life-Cycle Assessment

Controls typically last 10 to 15 years. Controls that are simple to use, easy to maintain and have relatively low first-cost that make them cost-effective in most situations include:

- Programmable thermostats.
- EMS-controlled temperature setback.
- Outside air temperature sensor to reset the temperature of heating hot water.
- Temperature reset of heating hot water based on temperature of return water.
- Optimum fan start/stop for fans and pumps.
- Warm-up cycle without outside air.
- Variable speed drives for fans and pumps.
- Wet bulb reset for cooling tower (instead of operation at fixed temperature).

Other controls need a life-cycle analysis. Examples of these include:
- An economizer control that allows outside air to be introduced while the chillers function, as long as the enthalpy of the outside air is lower than that of return air.
- DDC-controlled minimization of reheat in VAV systems.
- Oxygen trim for boilers and gas-fired chillers.
- Modulation of outside air based on CO₂ or VOC content.
- Fan cycling in garages based on CO content.

The same sensors are often shared for several control strategies, making the cost per control strategy lower in larger systems than in smaller ones. Analyses should be performed assuming that at least the minimum control system is already in place.

Controls need regular calibration to be effective. Failed sensors and false readings can waste considerable energy.

Series Matrix: Guide #9

|------------------------------|-----------------------------------|------------------------------------|-------------------------------|-----------------------------|-------------------------|-----------------------------------------|---------------------------------|----------------------------------------|----------------------------------------|-----------------|--------------------------------|-----------------------------------|----------------|--------------------------|

Additional Information

**Key Words for Internet Searches**
Programmable Thermostat, Outdoor Air Reset, Variable Speed Drive, DDC control, Wet Bulb Reset, Oxygen Trim, HVAC Optimization, Chiller Plant Optimization
High-Performance Renovation: Water Management

Philadelphia High-Performance Building Renovation Guidelines

The Role of Water and Irrigation Systems

Water is supplied for a wide variety of uses, including direct consumption by building occupants, cleaning (of both people and building elements), sewage transport, delivery of heat (e.g., hydronic-based heating systems), removal of heat (e.g., cooling towers, evaporative coolers, water loop heat pumps), air humidification, fire-protection (sprinkler systems), irrigation for landscaping, and process-based functions (e.g., manufacturing). With all of these applications, water consumption within a single building can be intensive, creating significant pressures on both the city’s fresh water resources (1) and its wastewater treatment facilities (2). Older buildings, in particular, often suffer from combinations of leaky plumbing, inefficient fixtures (toilets, faucets), and wasteful water-using equipment. Renovations offer the opportunity to repair or replace faulty and outdated elements, which ultimately reduces water losses.

System Integration

Water heating systems

A number of water-saving strategies (faucet aerators and controls, low-flow showerheads, water-efficient appliances) also reduce hot water consumption in the building, and can lead to downsizing of the domestic hot water heater.

Timing / Staging

Water conservation strategies should be considered early in the renovation process to determine if savings may be possible in conjunction with other plumbing or system upgrades.

For example, if older toilets are being replaced with new water-efficient models, waste lines may be downsized (if they are also scheduled to be replaced). Similarly, installing waterless urinals can eliminate the need to replace water feeds to urinals in renovated bathrooms (currently, approvals are needed to implement this measure).

In addition, fixtures that reduce hot water use can result in smaller domestic hot water heaters for the building. Finally, if landscape upgrades are within a project’s scope, the use of xeriscaping principles may eliminate the need for new or reworked irrigation systems.

If stormwater collection systems or wastewater treatment/recycling systems are contemplated, an early assessment of code and permitting requirements should be undertaken.

Terminology

**Aerator**: A device that entrains air into a water stream, causing the water to form small droplets. Aerators are typically used for faucets or showers to reduce water consumption while maintaining the feel of a full flow.

**Black water**: Wastewater from toilets, urinals, or other fixtures that must be treated as sewage.

**Delimiters**: Baffles used in cooling towers to minimize the escape of water mist that would otherwise be carried away by air drafts. Also known as drift eliminators.

**EPACT**: The Energy Policy Act of 1992. Included in this federal law were National Plumbing Standards that defined maximum water consumption values for various water using fixtures, including toilets, urinals, faucets, and showerheads.

**Gpm**: Gallons per minute. Used to define the maximum water flow rate for faucets and showerheads, typically at a specified water pressure (80 pounds per square inch is the EPACT Standard).

**Gpf**: Gallons per flush. Used to define the maximum water use rate for toilets and urinals.

**Grey water**: Wastewater from sinks, showers, washing machines, dishwashers, and other non-sewage fixtures.

**Potable water**: Drinkable water.

**Xeriscape**: An approach to landscaping that emphasizes water conservation and the reduction of fertilizers and pesticides. Xeriscaping is primarily accomplished through appropriate plant selection, highlighting native or climate-adapted species.
Cooling Towers

Strategies to reduce water use in cooling towers must be carefully coordinated with the performance parameters of the cooling tower. If too little make-up water is used, the performance of the cooling tower will be diminished; conversely, using excessive make-up water does not improve the cooling tower performance, but does waste significant amounts of water.

Stormwater management

Stormwater collection systems that provide water for irrigation or building uses will also reduce the amount of water discharged from the site. This can be a benefit for sites where stormwater discharge must be carefully controlled (see Guide #1: Site Issues and Improvements for more information).

Scale of Importance

1. **Plan first.** The time spent on planning can be saved many times over through system integration efficiencies and long-term operating savings.

2. **Fix leaks.** Leaks in piping or fixtures can result in enormous amounts of wasted water, and can potentially damage the building. Water leaks that saturate building materials can also lead to mold growths and associated health problems.

3. **Make simple, low-cost improvements at the earliest opportunity:** Adding aerators to existing faucets and changing showerheads are examples of simple, low-cost measures that can save significant amounts of water. These changes should be made wherever applicable, even when larger water-efficiency renovations (e.g., toilet replacements) are not possible.

4. **Replace older fixtures.** Older plumbing fixtures manufactured or installed before the EPACT requirements of 1992 are likely to use two to three times as much water as new fixtures. Replacing these older fixtures (including toilets, urinals, faucets, and showerheads) offers the best opportunities for significant water use improvements.

5. **Integrate water efficiency into any equipment or system upgrades.** When purchasing major new equipment (e.g., cooling towers), appliances (dishwashers, washing machines), plumbing fixtures, or irrigation systems, the premiums for water-efficient products are typically low (in many cases there is no premium). It is much easier to justify a small premium for water-efficient fixtures when the item is already going to be replaced, than to justify a fixture replacement based solely on water cost savings.

Water System Renovation Strategies

**Fix Leaks ($)**

Faucets, pipes, and toilets are prime sources of leaks. Plumbing systems should be carefully examined to determine the source and extent of leaks within a facility. Water meters can be used to check the overall amount of leakage in a building by taking measurements over a time period when no fixtures are in use. In addition to saving water, repairing leaks from pipes or fixtures can also avoid potential water-damage problems and mold growth.

**Install Aerators on Existing Faucets ($)**

Before the EPACT requirements of 1992, many faucets and showerheads had flow rates in the range of 3-6 gallons per minute (gpm). Today, inexpensive faucet aerators (3) can be installed on most existing fixtures to reduce their flow rates to 2.5 gpm (maximum), or even as low as 0.5 gpm. Flow rates should be determined based on the faucet use – for kitchen, pantry, or custodial fixtures the 2.5 gpm aerators may be a practical limit, while bathroom faucets still perform well at the lower flow rates. See the following section for a description of aerating versus laminar flow designs.

**Replace Faucets and Showerheads With Low-Flow Fixtures ($-$)**

When installing new faucets and showerheads, a number of low-flow options are available. By law, faucets and showerheads cannot use more than 2.5 gpm (at 80 psi). A number of products, however, are designed to perform well at even lower flow rates.

Most low-flow faucets and showerheads (4) use either an **aerated flow** (where air is mixed with the water to form tiny droplets) or a **laminar flow design** (which produces dozens of very close parallel streams of water). Faucets using laminar flow designs are rated as low as 0.5 gpm; as noted above these fixtures are typically appropriate.
Water Systems Renovation Strategies (cont’d)

where hand-washing is the primary purpose.

With showerheads, a number of manufacturers offer models rated at 2.0, 1.8, and 1.5 gpm (the lowest flow models may not be suitable for buildings that operate at low water pressure). Many of these products use sophisticated aerating techniques to produce a forceful, full- feeling flow. It is important, however, to compare products to assure satisfaction. Many low-flow showerheads also have flow-regulator levers to temporarily stop water flow during shampooing, soaping, etc.

Install Faucets With Automatic Shut-off Control ($$)

Faucets that are not fully shut off after use can waste significant amounts of water in relatively short periods of time. In general, there are two types of faucets that provide automatic shut-off control: metered-valve faucets and faucets with integrated electronic/infrared sensors.

*Metered-valve faucets* provide water for a preset amount of time (10 seconds is the minimum required by the Americans with Disabilities Act), then shut off. *Electronically-controlled faucets* (5) use infrared sensors to detect the presence of hands—the faucets turn on and off directly based on the sensor. In addition to saving water, automatic faucet controls can also save energy from wasted hot water. Electronic controls also offer the benefits of improved hygiene and lower maintenance because of their “no-hands” operation. Electronic controls are available with either battery operation or hook-up for an AC power supply.

Replace Older Toilet fixtures With New Water-Efficient Models ($$$-$$$$)

Most older toilets (those manufactured before the EPACT requirements were enacted) use between 3.5 to 5 gallons of water per flush. New toilets use 1.6 gallons per flush. In a typical commercial facility, where toilet flushing can represent almost half of the facility’s internal water use, the potential water savings from toilet replacements are enormous. Reductions in both water and sewer charges can often make toilet replacements economically viable (see Guide #12: Emerging Technologies, for information on dual-flush toilets).

Replace Older Urinal Fixtures With New Water-Efficient Models ($$$-$$$$)

As with toilets, urinal replacements can provide significant water savings in comparison to older fixtures. The EPACT standard for urinals is 1.0 gallons per flush; in addition, some manufacturers now offer models that use only 0.5 gallons per flush.

*Waterless models* (6) are the latest developments in urinals. Using a special trap design that contains a lightweight biodegradable oil, the fixtures allow urine to pass through while preventing odors. No water or flush valve is involved. Waterless urinals offer the benefits of significant water savings and potentially lower first-costs. Maintenance on waterless urinals is different from those of standard urinals; while it is not necessarily more maintenance, it does require that cleaning crews follow the manufacturer’s protocol. At this time, three manufacturers offer waterless urinals in the U.S. (currently, approval to install this measure is necessary).

Install Water-Efficient Dishwashers and Washing Machines ($$)

Look for appliances that carry the EPA’s ENERGY STAR label. In addition to saving energy, these models will also significantly reduce water consumption (most of the energy savings for dishwashers and washing machines, in fact, comes from the reduced use of hot water). The most energy- and water-efficient washing machines are horizontal-axis models—they can provide 30-50% water savings versus vertical-axis washers.

Install Delimiters and Additional Controls on Cooling Towers ($$)

In many commercial buildings, cooling towers (7) can consume between 20-30% of the facility’s total water use. Although water supplied to cooling towers is recirculated, a continuous percentage of the water supplied is lost through evaporation and drift.

Additional water is lost as “blowdown”—water that is purposely removed from the recirculation loop to prevent the build-up of mineral deposits and other contaminants. Water-saving strategies for cooling towers include the use of delimiters and automated blowdown systems with conductivity controllers.

*Delimiters* are essentially baffles that minimize the escape of water mist from the tower, and allow the droplets to collect and be recirculated. While delimiters reduce water consumption, they can increase the energy use. Take both aspects into account when specifying these devices. *Automatic blowdown systems* use conductivity controllers to determine how much water to bleed from the recirculating loop. By controlling the amount of blowdown, a corresponding amount of make-up water is conserved. *Conductivity controllers* must be...
Water Systems Renovation Strategies (cont’d)

set based on critical characteristics of the water supply, such as hardness, silica content, total dissolved solids, or algae.

Utilize Xeriscape Practices for Landscaping ($ - $$)

Xeriscaping (8) emphasizes the selection of native or climate-adapted plant species for use in landscaping. A full xeriscape approach starts with planning and soils analysis, and continues through plant selection, efficient irrigation (if needed), and the use of mulches or other appropriate maintenance techniques. The xeriscape approach leads to significant reductions in water use, while also minimizing the need for fertilizers and pesticides. First costs can be significantly decreased by reducing or eliminating the need for irrigation systems.

Install Drip Irrigation Systems for Non-Turf Planting Areas ($$)

For most planting areas other than turf grass, drip irrigation systems can be installed in lieu of sprinkler systems. Drip irrigation systems supply water at low pressure to emitters (such as soaker hoses) (9) or to bubblers that are located directly near the root zones of the plants to be watered. Unlike traditional sprinkler systems, little water is lost to evaporation or to overspray (e.g., water that lands on pavement).

Drip irrigation systems require careful planning to coordinate the system layout with the plantings. For aesthetic and security purposes, drip irrigation hoses can be buried and/or covered with mulch at the planting areas. Subsurface drip irrigation systems can also be supplied with grey water from the building or collected stormwater, if either of these water reclamation systems are present (see below and Guide #12: Emerging Technologies for more information, and note that currently, approval for reuse of greywater and stormwater is required).

Spray heads (10) use more water than drip irrigation systems but can still be made quite efficient by connecting them to rain and moisture sensors—so they do not irrigate during and after rain—and/or by installing a programmable control on the entire system—so spraying can be scheduled off at specified times during drought.

Install Rain Sensors and/or Moisture Sensors to Control Landscape Irrigation Systems ($$)

Most permanent sprinkler or drip irrigation systems are controlled via timers that schedule the hours of irrigation. Advanced rain or moisture sensor controls can save between 15 - 40% of annual irrigation water use by eliminating unnecessary watering. Rain sensors, which are mounted above grade, detect natural rainfall and shut the irrigation system off until the rain has stopped and the sensor has dried. Moisture sensors measure the moisture content of the soil, and prevent the irrigation system from watering when the moisture content is above a predetermined threshold. Advanced irrigation controls require initial calibration and periodic follow-up to ensure that the systems are functioning as intended.

Consider Stormwater Collection and Treatment for Reuse ($$$)

In urban areas, stormwater runoff from roofs and paved surfaces is typically directed to storm sewers. If collected on site, this water can be reused for irrigation or even for building uses (e.g., for cooling tower make-up water).

Stormwater collection systems are typically sized by assessing the amount of water needed for the intended end use (e.g., landscaping around the building). For most urban sites, stormwater is collected in holding tanks located underground or within the building. If the water is being used for subsurface landscape irrigation, it typically needs only to be filtered before being used. For building uses, the water must undergo further chemical and/or ultraviolet light treatment—these types of systems are typically designed by specialists who are familiar with all building and health code requirements. Currently, approval for reuse of stormwater is required.

Wastewater Treatment and Recycling ($$$-$ $$$)

Systems that collect the building’s wastewater (either greywater or blackwater) for on-site treatment and reuse are discussed in Guide #12: Emerging Technologies.

Use Environmental Materials ($)

Many plumbing fixtures (e.g., toilets, faucets) require the use of caulks and/or adhesives in their installation. In most cases, low-emitting products are available that minimize the release of harmful volatile organic compounds (VOCs). Sealants having a VOC content of less than 250 grams per liter should be considered for most applications.

Most older faucets and plumbing components (including the solder used to join elements) were manufactured with a higher concentration of lead than is now allowed. Replacing these components with new fixtures can minimize the risk of lead...
Water Systems Renovation Strategies (cont’d)

exposure from drinking water. New faucets and other devices that dispense water for drinking should be certified to meet the ANSI/NSF Standard 61, Section 9 - this assures that any possible lead leaching from the fixtures is below the threshold allowed by law.

Use Sustainable Construction ($-$)

Demolition and construction waste recycling should be instituted to divert as much waste as possible from the landfill. With plumbing systems the piping, faucets, drains and other components are typically made from non-corrosive metals such as copper or brass. These materials are routinely reclaimed from building demolition and sold for scrap. Similarly, steel or iron components can typically be separated for recycling.

Even the porcelain fixtures (toilets, urinals) can often times be recycled – the fixtures can be crushed for use as clean fill in civil works or building projects. In addition, with the emergence of retail materials reuse yards, fixtures in good condition can be resold (note: ReStore, located in Port Richmond, is among the first retail outlets in Philadelphia—see discussion in the Introduction for more information).

Benefits

- Water and Sewer Fee Savings
  Water efficiency measures lead to direct savings in metered water charges, and in many locations, in sewer fees (which are often based directly on water use).

- Energy Savings
  Many water saving features also reduce a building’s demand for hot water, resulting in direct energy savings. In addition, reductions in water use (both internally and for irrigation) can save pump energy.

- Resource Conservation
  Fresh, potable water is an important resource that is often undervalued. Using water wisely helps to ensure that existing fresh water sources can continue to meet the needs of present and future generations. In addition, water conservation minimizes the load on municipal sewage treatment facilities, reducing the need for increased infrastructure.

Life-Cycle Assessment

Some water-saving strategies, such as the installation of faucet aerators or replacement showerheads, can be implemented at very little first-cost. The savings these measures provide in both water costs and energy costs (for reduced hot water use) will usually pay back their initial costs in one-two years (assuming they are replacing older, high-water consumption fixtures). These fixtures require no more maintenance than the fixtures they replace, resulting in excellent life-cycle value.

Toilet and urinal replacements can save significant water and sewer fees, but clearly require a higher first cost investment. The cost/benefit of this type of retrofit needs to be assessed on a project-specific basis; however, some case studies have indicated a payback period of 8-10 years. If the fixtures are in need of replacement because of general wear, there is generally no premium associated with the water-efficiency aspect.

Specialized products such as waterless urinals or faucets with electronic controls must also be considered on a project-specific basis. With these types of products, maintenance issues should also be factored in. The waterless urinal manufacturers generally claim that maintenance is reduced over the long term with their products; the lack of flush valve repairs offsets the costs of periodically replacing traps and adding trap-seal fluid. With electronic faucets, batteries may need to be replaced if a permanent outlet is not installed. Additional considerations, however, such as improved hygiene, ease of cleaning, and fewer leaks, work in favor of these faucets over their life cycle.

Conductivity controllers for cooling towers can be retrofitted to existing systems or specified as part of a new system. The controllers must be calibrated periodically and, depending on the type used, the sensors may need to be replaced at least once over the life of the tower. From a life-cycle
Life-Cycle Assessment (cont’d)

perspective, these costs are normally offset by the reduction in water use and reduced use of chemicals in the cooling tower operation.

With landscaping, the xeriscape approach has the potential to save first-cost (if it eliminates irrigation), save water costs, and save fertilizer or pesticide application costs. In many cases (though not all), the overall level of maintenance for a xeriscaped area (including mulching, trimming, weeding, etc.) is less than what is required for traditional turf-intensive landscapes. A reduction in landscape maintenance can quickly offset additional first-costs that may be associated with the plants themselves.

Series Matrix: Guide #10

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Additional Information

Key Words for Internet Searches
Water efficiency, aerators, infrared faucet controls, low-flow showerheads, waterless urinals, ENERGY STAR appliances, cooling tower delimiters, xeriscape, drip irrigation, rain sensor, moisture sensor, storm water collection
High-Performance Renovation:
Material Selection for Sustainability

Philadelphia High-Performance Building Renovation Guidelines

The Role of Sustainability

Sustainable or "green" development is defined in many ways. LEED, the rating system of the US Green Building Council, is concerned with:

• sustainable sites
• water conservation
• wastewater reduction
• decrease in energy use and atmospheric pollution
• conservation of materials and resources
• better indoor environmental quality (including IAQ, and thermal and visual comfort)
• a process to approach sustainability issues.

LEED does not address all aspects of sustainability, and even though it is evolving, it will never be all-inclusive. Also, not all that LEED contains may be appropriate for a given project, but LEED constitutes a good starting point.

Sustainability is woven throughout all the other Guides. This Guide sketches a general framework and discusses issues related to resource conservation and interior finishes in more depth. Many aspects of sustainability are already finding their way into common practice; more will be absorbed in the future. In the end, sustainability concerns should become no different from other design, construction and maintenance issues, such as comfort or structure.

Timing / Staging

Sustainability is included successfully at no-cost or low-cost if it is considered from the very beginning.

Integrated Design and Planning. The process requires a shift from a linear, sector-by-sector design approach to a team-based approach (owner, all building, site, maintenance and operating professionals and end-users) that focuses on whole systems and interactions, life cycle costs, resource efficiency, waste minimization, building adaptability and occupant health.

Set goals. Is a LEED rating possible? Will the building be exemplary? Within the universe of sustainable measures, will there be any aspect emphasized (e.g., energy efficiency because it has a payback; IAQ: perhaps recycling or water conservation because of unusual opportunities)? Recognize potential incremental costs and/or potential savings associated with these goals.

Assign and schedule resources. Even with experienced design and management teams, there is additional effort from the part of the client agency, of the agency supervising the design and construction, of the design team, and of the construction team. There may be a need for outside consultants. Ideally, the supervising agency will have a point person to ensure that the sustainability goals are achieved. The same should happen within the design team. Recognize that sustainable design requires more work in the early design stages than usual; there is also more emphasis on ensuring that once completed, the building functions as envisioned (commissioning). The investment in planning and commissioning results in high performance buildings that can achieve first cost and life cycle savings.

Create a time line. Some activities are on a critical path – e.g., diversion of materials from the waste

Terminology

Commissioning: a systematic, quality assurance process that examines and optimizes building design features and system performance so buildings function as intended. Commissioning can be applied in new construction, post construction (re commissioning/continuous commissioning) and existing buildings (retro commissioning).

Embodied energy: All energy used to extract raw materials, manufacture, transport, and install a product.

IAQ: Indoor Air Quality.


U.S. Green Building Council: Organization dedicated to the promotion of sustainable practices in buildings.

VOC: Volatile organic compound. Airborne molecules emitted from the chemical constituents of liquids and materials that can be noxious or unpleasant to building occupants.
The Role of Sustainability (cont’d)

stream during demolition. Others can be addressed later in design – e.g., selection of low-VOC paints.

Create an action-items report. This detailed report delineates the strategies to be followed to achieve each sustainability goal (e.g., how to procure recycled-content tiles and from where, or how to obtain 20% energy cost reduction vs. the ASHRAE/IESNA Standard 90.1). It also evaluates the feasibility, or probability of success of each strategy, given the specifics of the project (e.g., secure, likely, possible, not likely, not feasible). Finally, the report shows associated costs and responsibilities for each sustainability goal. This document should be updated at least once, during the construction documents phase.

Periodically review the status of sustainable measures. While not all work meetings need to discuss sustainability, one discussion per design phase is not sufficient.

Construction documents and the bid documents must clearly state what is expected from construction contractors, including submittals of documentation confirming sustainability actions (e.g., evidence of reuse of materials, or of good IAQ practices during construction).

Review submittals with attention to sustainability. It is easy for sustainability goals to falter during this phase.

Commission the building, if at all possible. This is one of the most effective sustainability actions that can be taken (and required if LEED certification will be sought).

Train maintenance personnel to understand not only what they have to do, but also why.

System Integration

When designers create plans and elevations, they continuously have structural implications in mind. The same should be true for sustainability issues. Any aspect of a building that is “pasted on” at the end – be it sustainability, noise abatement, security, even such basic issues as summer cooling – will be expensive, less successful than it could have been, or both.

Within sustainability measures there are strong synergies between groups of measures. For example:

- Vegetated roofs, heat island effect, reduction in storm water discharge, conservation of potable water;
- Energy efficiency, reduction in atmospheric pollution, daylighting, views, thermal comfort;
- Waste stream reduction, recycled content and material reuse.

Scale of Importance

Each project is unique, but a few guidelines should be applicable to most cases:

1. Do not harm existing natural and valuable on site historic resources. Where feasible and worthwhile, restore these elements (e.g., remove boarded-up covers on overhead glazing).
2. Do not negatively affect other sites.
3. Make the site a success, both in the satisfaction of the occupants and in meeting economic goals. The first-costs associated with some sustainability techniques (e.g., gray water, green roofs, and some renewable energy technologies) will be significantly higher than traditional approaches until the concepts, techniques, and materials become common-practice. Subsidies for such technologies are still important to level the playing field.
4. Consider developing / renovating the site to be environmental at several levels:
   - during construction;
   - during operation, while occupied;
   - at the end of its useful life (disposal/recycling/reuse).

Material Selection for Sustainability

Resource Conservation

The construction, renovation, and maintenance of buildings uses significant resources that our society extracts from nature, processes into materials, and often landfills after relatively brief use. These activities contribute to resource depletion, habitat destruction, pollution from energy production and manufacturing, and generation of solid waste. To increase material use efficiency, consider the popular maxim Reduce, Reuse and Recycle at the beginning of a renovation project.

Sustainable development, however, has other important components. Consider whether indoor air quality (IAQ), visual comfort and adequacy of the space for the tasks performed within will be best served by renovation or new construction. For example, IAQ may not be automatically better after the renovation of an existing building, and sometimes harmful materials (e.g., lead and asbestos) are abated or encapsulated, while other times materials that do not pose an immediate health risk must be left
Material Selection for Sustainability (cont’d)

in place as-is. Additionally, the HVAC systems may not operate as well as in a new building, etc. The decision between renovation and new construction, or between small building improvements and gut rehab, takes into account these and many other factors. Nonetheless, within the greater context of sustainability issues, it is important to make a concerted effort for resource conservation.

- **Reduce and Reuse**
  One important sustainability argument in favor of renovation projects is that such projects use fewer resources than new construction, reducing the need for virgin resources. Leaving structure and/or infrastructure exposed (e.g., exposed ceilings or brick exterior walls), reduces the need for finishing materials, such as drywall. In addition, materials that already exist in a building have fewer noxious emissions than the same materials, newly installed.

  Reuse existing structures where feasible, especially if they have historic significance. If removing materials during renovation (e.g., millwork, doors, architectural metals, bricks), contact one of the growing number of material reuse yards/stores that collect goods and materials from construction projects for resale and reuse in other local projects.

  For major renovation of light-framed structures, consider deconstruction (the systematic disassembly of buildings and harvest of materials for reuse or remanufacture) instead of demolition. The City is currently exploring deconstruction options related to demolition activities within the parameters of the Mayor’s Neighborhood Transformation Initiative.

- **Recycle**
  A high percentage (up to 85%) of construction and demolition waste is reusable or recyclable. Some can be reused right on site (1). Sorting of demolition waste for recycling can be done by the individual contractors on site, as generated, or off-site through a waste management subcontractor. Start-up costs for on-site waste management include renting dumpsters for each recycling/salvage category (e.g. steel, pipe, glass, wood) and training subcontractors to sort their waste. These costs are often redeemed through avoided landfill tipping fees and/or payment by processing centers for the material. A list of local processing centers for recyclable goods is typically available from the local government and/or the internet.

  **Material Selection**
  Many materials can be assessed according to the environmental characteristics enumerated below.

  - Off-gassing and release of toxic compounds during building use
  - Durability and maintainability
  - Toxicity during manufacturing and disposal
  - Recycled content, and ability to be recycled
  - Sustainable harvesting of materials
  - Direct environmental impact (air, water, soil, life)
  - Embodied energy

  The list is not all-inclusive. Project-specific circumstances and goals may dictate that different criteria be added; this process, however, applies to any decision in the design and construction of buildings.

  Since many products score well against a few of these criteria and poorly against others, prioritization must occur. Consider qualities that affect the indoor environment first. The top two criteria from the list have the greatest direct impact on building occupants.

  **Off-gassing and toxic compound release**
  Most new materials off-gas volatile organic compounds (VOCs) and other constituent compounds, such as formaldehyde. The two most common specifications for selecting materials that do not contribute to poor indoor air quality are “VOC-free” (2), “low-VOC” and “without added urea formaldehyde.” VOCs are not necessarily harmful or unpleasant (the scent of perfume is carried by VOCs), but certain types of VOCs are associated with most of the odors and air-quality issues that can make occupants uncomfortable or sick. VOCs also contribute to smog. A “VOC-free” designation for a product denotes the absence of VOCs identified by EPA — it does not mean that the product emits no VOCs at all (see “VOC emissions potential” on page 5 for further detail).

  Urea formaldehyde, most commonly associated with composite wood glues, is an irritant that affects an estimated 10 - 20% of the general population, according to the National Academy of Sciences.

  1 Courtesy, National Park Service

  Deconstruction and reuse on site

  2 Courtesy, Benjamin Moore

  VOC-free paint
Material Selection for Sustainability (cont’d)

Though VOC and urea formaldehyde content is not a direct indicator of a product’s air pollutant emissions once installed, it is a general indicator of a product’s potential to emit. Moreover, it can be measured and accounted for on a per product basis. In addition to material selection, material installation also has a considerable impact on indoor air quality and occupant comfort.

Materials emit VOCs in one of two trends: “high and short” or “low and long.” “Wet” products, such as paints, sealants, adhesives, caulks and sealers, tend to off-gas VOCs at relatively high rates during application and curing. Once cured, these products emit VOCs at a substantially lower rate (if occupants are present during the time of wet product application and curing, as is often the case with renovation and retrofit projects, wet products can generate repeated complaints about odor and irritation). “Dry” products, by comparison, generally emit VOCs at a lower rate, but over a longer term.

Dry emitting products include flooring coverings with plasticizers and engineered wood with formaldehyde binders.

Another fact to consider is that dry and soft materials including textiles, carpeting, acoustical ceiling tiles, and gypsum board can absorb the VOCs emitted by wet materials and release them over a prolonged period of time. To mediate this, schedule the installation of dry materials after wet during construction (to the extent practical) and protect dry materials during times of painting and renovation.

Selecting low-VOC and urea formaldehyde-free products has the greatest impact on indoor air quality when the material will be (a) used in large quantities throughout the building or in a particular space; (b) have a large surface area exposed to an occupied area and/or supply ventilation air; and (c) has a particularly high potential to emit VOCs or strong odor. Primary examples include adhesives, joint sealants, paint, carpet, and composite wood. For these product types, LEED references the following standards:

- **Adhesives**: The VOC content of adhesives shall not exceed the limits listed in chart 1, as defined in Regulation 8 (Organic Compounds), Rule 51 (Adhesive and Sealant Products) of the Bay Area Air Quality Management District of the State of California.

- **Joint Sealants**: The VOC content of sealants and sealant primers shall not exceed the limits listed in chart 1, as defined in Regulation 8 (Organic Compounds), Rule 51 (Adhesive and Sealant Products) of the Bay Area Air Quality Management District of the State of California.

- **Paints**: The VOC content of interior paints, interior primers, and anti-corrosive paints used in interior applications shall not exceed the limits listed in chart 1 (see continuation on next page), as defined in the Green Seal Environmental Standards for Paints (GS-11, dated 5/20/93) and Anti-Corrosive Paints (GC-03, dated 1/7/97), of Green Seal, Washington, DC.

Quality as well as VOC content of paint can be referenced in Master Painters Institute (MPI) Approved Product List. In addition to low VOC paints, the California Air Resources Board produces updated “VOC Limits for Architectural Coatings” to address VOC limits of fire retardant coatings, stains, waterproofing sealers, etc.

- **Aromatic Compounds**: The product must contain no more than 1.0% by weight of the sum total of aromatic compounds. Testing will be performed if these compounds are determined to be present in the product during a materials audit.

- **Additional Chemical Component Restrictions in Paints**: To the extent feasible, interior paints, interior primers, and anti-corrosive paints used in interior applications shall comply with the following chemical component restrictions of the Green Seal Environmental Standards for Paints (GS-11, dated 5/20/93) and Anti-Corrosive Paints (GC-03, dated 1/7/97), of Green Seal, Washington, DC. Compliance requires manufacturers to eliminate the following chemical compounds from the manufacturing of the product:
  - Halomethanes: methylene chloride
  - Chlorinated ethanes: 1,1,1-trichloroethane
  - Aromatic solvents: benzene, toluene (methylbenzene), ethylbenzene
  - Chlorinated ethylenes: vinyl chloride
  - Polynuclear aromatics: naphthalene
  - Chlorobenzenes: 1,2-dichlorobenzene

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**Chart 1. VOC Content**

Units in grams /per liter, less water and less exempt compounds.

<table>
<thead>
<tr>
<th>Adhesives</th>
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<tbody>
<tr>
<td>Wood flooring adhesive</td>
<td>100</td>
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<tr>
<td>Rubber floor adhesive</td>
<td>60</td>
</tr>
<tr>
<td>Subfloor adhesive</td>
<td>50</td>
</tr>
<tr>
<td>Ceramic tile adhesive</td>
<td>65</td>
</tr>
<tr>
<td>VCT, linoleum, sheet vinyl adhesive</td>
<td>50</td>
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<tr>
<td>Cove base adhesive</td>
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<tr>
<td>Drywall and panel adhesive</td>
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<td>Indoor carpet adhesive</td>
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<tr>
<td>Carpet pad adhesive</td>
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<td>Contact Adhesive</td>
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<tr>
<td>Multipurpose construction adhesive</td>
<td>70</td>
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<tr>
<td>Structural glazing adhesive</td>
<td>100</td>
</tr>
<tr>
<td>Single-ply roof membrane adhesives</td>
<td>250</td>
</tr>
<tr>
<td>Adhesive primer for plastic</td>
<td>250</td>
</tr>
<tr>
<td>Adhesive Primer for Traffic Marking Tape</td>
<td>150</td>
</tr>
<tr>
<td>Structural Wood Member Adhesive</td>
<td>140</td>
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<tr>
<td>Sheet Applied Rubber Lining</td>
<td>850</td>
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<tr>
<td>Operations</td>
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<td>Substrate Specific Applications:</td>
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<tr>
<td>Metal to metal</td>
<td>30</td>
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<tr>
<td>Plastic foams</td>
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<tr>
<td>Porous material (except wood)</td>
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<tr>
<td>Wood</td>
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<tr>
<td>Fiberglass</td>
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<tr>
<td>Architectural:</td>
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<td>Single Ply Roof Material Installation:</td>
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<td>Non-membrane Roof Installation:</td>
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<tr>
<td>PVC Welding</td>
<td>480</td>
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<tr>
<td>Other:</td>
<td>420</td>
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<tr>
<td>Sealant Primers:</td>
<td></td>
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<tr>
<td>Architectural (Non-porous installation):</td>
<td>250</td>
</tr>
<tr>
<td>Architectural (Porous installation):</td>
<td>775</td>
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</table>
Material Selection for Sustainability (cont’d)

- Phthalate esters: di (2-ethylhexyl) phthalate, butyl benzyl phthalate, di-n-butyl phthalate, di-n-octyl phthalate, diethyl phthalate, dimethyl phthalate
- Miscellaneous semi-volatile organics: isophorone
- Metals and their compounds: antimony, cadmium, hexavalent chromium, lead, mercury
- Preservatives (antifouling agents): formaldehyde
- Ketones: methyl ethyl ketone, methyl isobutyl ketone
- Miscellaneous volatile organics: acrolein, acrylonitrile

Carpet Products: Carpets, carpet tiles, carpet pads, and adhesives shall meet or surpass all criteria of the “Green Label” Indoor Air Quality Test Program established by the Carpet and Rug Institute (CRI) of Dalton, Georgia.

Composite wood: Composite wood and agri-fiber products must contain no added urea-formaldehyde.

VOC emissions potential - Not all VOCs are regulated and reported in standard VOC testing procedures. It is therefore possible that products may contain VOCs or semi-volatile organic compounds that are unregulated, while still claiming to be “VOC-free.” In addition, products may release VOCs upon application that were not originally contained in the product, but formed through chemical reactions with other VOCs in the air and/or by deterioration under normal environmental conditions (e.g., exposure to sunlight).

To obtain additional information on a product’s VOC emissions potential, request emissions data from product manufacturers that have performed Environmental Chamber Testing (ECT). Another resource is the independent Greenguard Program (www.greenguard.org) which lists products that have undergone ECT and met emissions criteria for VOCs, formaldehyde, and other substances as set by the EPA, Occupational Safety & Health Administration (OSHA), State of Washington, and other organizations.

- Toxicity during manufacture and disposal
  Chemicals in some products can be harmful to production workers, to the IAQ in buildings, and to the environment when discarded. For example, mercury, present in fluorescent lamps, constitutes a health hazard during manufacturing and disposal. Chlorine, present in many bleaching agents, can combine with organic matter readily available in the environment to create organochlorines, which bioaccumulate up the food chain and are suspected to cause reproductive and other medical problems.

Alternatives exist, but not for all products and not always without other negative side effects. As the environmental sciences progress, more information becomes available. In some cases, as for low-mercury fluorescent lamps, the choice is easy, constrained only by availability and cost. In other cases consider the suitability of the material for the application. Many resources available on the internet list potential toxins in cleaning agents and building materials. The EPA’s website includes the Persistent Bioaccumulative Toxin (PBT) Chemical Program that identifies and provides information on avoiding these hazardous chemicals.

- Recycled content, and ability to be recycled
  Most building materials can be specified with recycled content. Refer to the "Resource Conservation” sections of the other Guides. Some materials can be reconstituted and then reused again for a different purpose. Examples include: nylon carpet fibers that are reutilized for other carpets, crushed glass that is aggregated for terrazzo-style countertop tile applications, and plastic bottles that are melted and integrated with carpet fibers or bathroom materials.

- Renewable materials and sustainable harvesting
  Rapidly-renewable materials are ready for harvest within ten years of planting or shoot. Examples include linseed oil and jute (constituent materials of linoleum), bamboo (Fig. 4 on previous page).
Benefits
Sustainable buildings are more energy-efficient, pollute less and, in general, place less pressure on the environment. An increasing body of data shows that productivity increases significantly in sustainable buildings. In general, about 80-90% of the cost associated with a building is related to salaries. Even a tiny improvement in productivity has major economic advantages.

Life-Cycle Assessment
A comprehensive method of evaluating products considers their effect on people and environment, from extraction through disposal or reuse. Two computer programs can help: BEES (Building for Environmental and Economic Sustainability) by the National Institute of Building Sciences, and the ATHENA Environmental Impact Estimator from the ATHENA Sustainable Materials Institute. It is impossible to confidently assign a specific weight in the life-cycle evaluation to each of the diverse sustainability factors. For instance, if human health is rated 10, should environment preservation be 7? 6.5? 8.3? What is more damaging to human health – long-term lower exposure given by a certain material, or short-term higher exposure that may be given by another?

The LCA method may be more suited, for now, to research the desirability of certain products for a building program rather than for a specific building. In this context, when used with a clear understanding of the assumptions, and of the uncertainty associated with these assumptions, it provides another useful indicator.

Energy is expended to extract and transport raw materials, manufacture the product, and then transport this product and place it on-site. This is the embodied energy. A product with lower embodied energy, from this perspective, is more sustainable than one with higher embodied energy. The picture is not complete, however, without assessing the useful lifespan of the product, and the energy expended for disposal (see Life-cycle Assessment below).

While useful as an indicator that complements others, the embodied energy calculation depends greatly on how broad a view is taken, and great care should be taken if used as a primary factor in decisions. For instance, when assessing the energy required for manufacturing, does the count include the energy expended by people to reach the workplace or to treat occupational disease? The calculation for embodied energy will yield different results depending on these assumptions.

Additional Information
Key Words for Internet Searches
Sustainability, recycling, reuse, indoor air quality, VOC, urea formaldehyde

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The Role of Emerging Technologies

Emerging technologies of yesterday are now commonplace. It was less than 20 years ago that low-e windows (see Guide #4) first became commercially available. Now they are commonly used, and the cost premium for them is very small. Similarly, new lamps, HVAC equipment, and automated controls have been invented and brought to the marketplace. Consider the commercial success of the light-emitting diode (LED), now universally used for exit signs, the compact fluorescent lamp, and the dimmable electronic ballast (still gaining market share). In some instances the innovation consists of extending the range of an already-established application – such as in condensing boilers that can now deliver as much as 3.3 million Btu/hr (older models delivered up to 1 million Btu/hr).

The purpose of this guide is to examine today’s cutting edge of building technologies with an eye toward how they might be applied in future building renovation. Use of the emerging technologies described here will generally be limited to projects with significant demonstration value.

Timing / Staging
Consider the deployment of emerging technologies throughout the design process. First costs can be controlled only by integrating these systems with the rest of the building.

Assess early-on the permitting needs for wastewater treatment and wind turbines. If you consider a large photovoltaic array, ensure that the location will not be shaded by future buildings or trees, and consider securing solar access rights.

System Integration
All emerging technologies must be integrated into the planning for conventional systems. An add-on approach increases costs.

Scale of Importance
1. **Plan first.** The time spent on planning is saved many times over during operations. This is especially true for advanced technologies, where it is important to be fully aware of all implications (see, for instance, issues of shading for PV, noise for wind turbines, health testing for black water systems).
2. **Consider emerging technologies for high-quality buildings only.** Advanced technologies should not be funded at the expense of basic building elements that beneficially affect day-to-day use, such as features that improve air quality or the use of natural daylight.
3. **Understand and account for emerging technology maintenance issues.** Some measures require little additional care or effort, such as insulating concretes and Building Integrated Photo Voltaics (BIPV). Some measures have little additional operating impacts, but require expensive overhauls in out years—fuel cells (at every five to seven years) are a good example. Others, like the black water systems, need continuous attention.

Terminology

**Effluent:** Wastewater.

**Hologram:** Interference pattern printed or stamped on a film or glass substrate using laser beams.

**Inverter:** Device that changes the direct current (DC) being supplied by the PV or wind turbine into alternating current (AC).

**Photovoltaic (PV) cell:** A multilayered device that converts sunlight into electricity when photons cause the electrons to cross the boundaries between the layers, thus creating an electrical current. The cells produce direct-current (DC) electricity, which must then be inverted for use in an AC system. Multiple cells compose a panel and multiple panels are connected in an array.

**Potable water:** Drinkable water.
Emerging Technology Strategies

WALLS AND ROOFS

• **Insulating concrete with synthetic aggregate** - Construction Technology Laboratories in Skokie, Illinois has developed a highly insulating concrete that uses synthetic aggregates instead of stone (R-8/inch as compared to about R-1/inch for typical, normal weight concrete and R-5/inch for lightweight concrete made with natural aggregates).

The synthetic aggregate concrete is useful for **applications that require relatively low structural strength**, such as low-rise construction, balconies and exterior shading devices. This insulating concrete can be used in areas where the structure itself creates the thermal bridging. In particular, it eliminates the thermal bridging created by balconies, a problem that cannot be mitigated with conventional methods. In another potential application, a swimming pool structure that uses synthetic aggregate concrete would be less prone to condensation. Because of its relatively high first-cost, however, the product has not been marketed.

• **Concrete with recycled glass content**  
  Columbia University has developed a concrete that incorporates glass from recycling. This glass, already broken (not from intact bottles), is ground to different degrees of coarseness before being incorporated in the concrete. The glass displaces some of the cement and confers a distinctive appearance to the concrete surface. The product can be used for exterior wall finishes, for paving, and for interior surfaces such as flooring, lavatory surfaces, and toilet partitions.

• **Hygro-Diode Membrane**  
  A self-drying vapor retarder for roofs that can be used for kitchens, swimming pools, data centers, museums, and other spaces that maintain high humidity levels in winter either because of the activities within or because moisture is added through the HVAC system. **Such spaces sometimes have a vapor retarder (e.g., polyethylene sheet) above the ceiling**; however, undetected roof leaks can cause damage. The self-drying vapor retarder can resolve this problem.

With traditional vapor retarders above the ceiling, if a leak is not repaired promptly, water accumulates above the vapor retarder. From there it destroys some types of roof insulation through freeze/thaw cycles (see Guide# 3: Upgrading Exterior Walls), reduces the R-value of most insulation types (except for polystyrene), promotes condensation and mold, and can eventually infiltrate into walls, causing damage at remote locations. The self-drying vapor retarder, commercialized as the Hygro-Diode Membrane (HDM), consists of a layer of synthetic felt with vapor-resistant plastic strips applied in a staggered fashion to both sides of the felt. Liquid water that reaches the HDM from above is absorbed by the felt and released into the space below through a vapor-permeable finish (to be specified by the architect), thereby resolving very small leaks. Greater leaks become apparent because of wetting of the ceiling finish, and signal that the roof membrane must be repaired.

HDM can also be used for walls that need a vapor retarder to the interior, but that may accumulate water behind this vapor retarder through accidental wetting or because of premature enclosure of wet-applied insulation. While HDM offers additional safety against water damage, it is best that water not be trapped in walls and roofs in the first place. The Hygro-Diode Membrane has been used in Europe for several years.

ADVANCED GLAZINGS

This is an area of sustained innovation. Two examples include:

• **Switchable electrochromic glazing** - This glazing is transparent, but when an electric current is applied, it becomes opaque. Theoretically, the visible transmittance decreases as the electricity increases in intensity. A curtain wall application pairs electrochromic glass for the vision panel with a PV spandrel panel (see "Distributed electricity production" below). As the solar radiation gets stronger, the PV panel produces more electricity and reduces the visible transmittance of the glass to a greater degree. This glazing was first manufactured and installed in a few U.S. buildings in the mid-1990s; then production was discontinued. In its new and more technological-advanced version, this glazing is being developed and marketed by SAGE Electrochromics, Inc. of Faribault, Minnesota.

• **Holographic film for daylighting** - in this glazing, a holographic film is laminated between two glass panes at the top portion of tall glass windows. The holographic film redirects...
Emerging Technology Strategies (cont'd)

diffuse light toward the ceiling (i.e., diffraction). Light bounces off the ceiling and reaches deeper into the space, beyond the 15-foot perimeter that can be daylit with windows.

The application of holographic techniques to glazings is still in the development and demonstration stages (Lawrence Berkeley Laboratory has been contributing much of the R&D), but elicits much interest because, if successful, it will play the role of light shelves in areas where these devices cannot be specified because of structural or aesthetic reasons.

At present, the technology has several limitations including applications in direct sunlight, because it may cause color dispersion (although light-guiding holographic materials for direct light are under development) and for vision glazing, because it may distort the view. The current application is for decorative purposes, but the industry anticipates daylighting applications in the near future.

INDIRECT DAYLIGHTING TECHNIQUES

• Light pipes (3) and fiberoptics (4) - Roof monitors and skylights are commonly used to introduce daylight into core spaces of top floors, but they can also be part of a system that conveys this light several floors below through light pipes and fiberoptics. Once daylight reaches its destination, it can be released into the space through a typical light fixture, or along the length of the light pipe or fiberoptic tubing.

Light pipes are actually tubes lined with a film. Fiberoptics are plastic or glass cables, similar to the ones employed for telecommunications. Both conduct light along their length with relatively high efficiency if the light reaches them at an angle that does not diverge much from the direction of propagation.

Since daylight at Philadelphia's latitude is highly variable in direction, it must be guided on the proper path by a sun-tracking system. The system can be constructed of focusing mirrors that follow the sun's movements and beam its radiation onto a fixed skylight. It can also consist of a mobile solar collector that tracks the sun and is connected to the light conduits. The former system has been used in several buildings in conjunction with light pipes, but is not commercially-marketed. The moving collector is sold by the Himawari Corporation.

Both systems are effective but expensive, and require significant maintenance because of the mechanical parts involved with sun tracking. Under a grant from U.S. Department of Energy, Steven Winter Associates, Inc. developed a tracking solar collector that is based on refrigerant expansion (instead of motors). This system is somewhat less efficient than the Himawari, but will be available at a fraction of the cost and with much lower maintenance if it moves from prototypical stage into production.

ELECTRIC LIGHTING

Fiberoptic light transmission - the source of light is remote, releasing most of its heat in a vented area; the light itself is transmitted through fiberoptic conduits to where it is needed. Most applications involve theater performing spaces or accent lighting, but fiberoptic light transmission has been used for space illumination (mostly outside the U.S.).

DISTRIBUTED ELECTRICITY PRODUCTION

Photovoltaics, Wind turbines and Fuel cells

Philadelphia's cloudy climate is not ideal for solar-powered electricity generation, nor is the potential for wind particularly high. But as the efficiency of electricity generation increases and the cost of the equipment diminishes, these technologies will become more attractive even in suboptimal locations such as Philadelphia. By way of comparison, the best location for high-efficiency boilers is Alaska, but nobody questions their economic viability in the Mid-Atlantic area (and even as far south as Texas).

Climate is not very important for fuel cells, but first-cost creates an obstacle. As with photovoltaics and wind turbines, this cost will decrease when mass production takes hold. The development of these three electricity generation technologies is also spurred by other factors:

• Increased concern about global warming and ozone depletion.
• Heightened interest in power backup.
• Potential for spikes in fuel prices, and high probability of significant increases over the long term.
• Technology transfer from other areas, such as space travel for PVs and car transportation for fuel cells.
Emerging Technology Strategies (cont’d)

- Photovoltaics (PVs) - PV cells have efficiencies of about 20-25% in the lab and about 10% - 12% in actual use, below the 30% maximum theoretical efficiency that can be attained. Most commercially available PV cells are made of highly purified silicon. A few manufacturers produce copper indium diselenide (CIS) panels, and PVs with other materials are in various stages of development. The search for non-silicon alternatives for PV is mainly driven by attempts to reduce costs.

PV systems can be stand-alone or connected to the utility grid (grid-connected). A stand-alone system is typically composed of a PV array, charge controller, disconnects and batteries, and is sized to meet the maximum load. A grid-connected system does not need batteries, except if blackout protection is desired.

An inverter is needed anytime the loads being served are alternating current (AC) and for all grid-connect systems. Inverters can be a separate piece of equipment or can be integral to the PV panel. Generally, a grid-connected system has the more favorable life-cycle cost.

There are currently three basic types of PV cells:

- Single or mono-crystalline cells are the most expensive but also the most efficient; they produce 11 to 12 watts of DC power/sf at peak and have a material cost of approximately $65 to $75/sf.

- Polycrystalline or multicrystalline cells produce about 10 watts of DC power at peak/sf and have a material cost of about $50/sf.

- Amorphous or thin-film cells produce about 4 to 6 watts of DC power/sf at peak and have a material cost of about $30 to $40/sf.

Costs listed are retail costs for the PV arrays only. Additional charges apply to other equipment such as batteries and charge controllers (for emergency back-up and stand-alone systems), disconnects, and inverters. The expenses for auxiliary equipment amount to a smaller percentage of the cost per square foot for large arrays. The cost of a small installation can be reduced by using all electricity when produced (i.e., no need for batteries) and by employing DC appliances fed only by the PV array (e.g., DC fluorescent lighting or a vent fan). Note that even though the current cost per square foot is high, PVs can be installed in small areas, at a relatively low total cost.

Appearance and Size - PVs can be opaque or translucent. Opaque PVs typically are dark blue or black, with other colors available at higher cost and lower efficiency. Typically, the separation between individual cells in monocrystalline PV panels is very pronounced, while multicrystalline panels have a homogeneous crystallized look, and thin-film panels have a solid color.

A translucent crystalline silicon assembly typically consists of 5-inch-square PV cells separated by 1 inch clear glass areas. This results in a grid pattern having about 17% light transmittance with 8 watts/sf peak power production, at a material cost of approximately $120/sf, including the grid-tie inverter. It is available in most custom sizes up to 52 inches by 65 inches.

A translucent amorphous silicon assembly typically consists of laminated glass and a thin PV-film layer that results in a linear clear and dark glass pattern with 7-10% light transmittance and about 4 watts/sf peak power production. It is available in 2 feet by 4 feet, 4 feet by 6 feet, etc. sizes. The material-only cost may be in the range of $80/sf, including the grid-tie inverter.

Building Integration - PVs can be mounted on stand-alone panels that require supports or can be made part of a building shell. The latter are referred to as Building Integrated Photovoltaics (BIPV). BIPV systems are an integral part of the building aesthetic and must be considered from the schematic phase of a project. The PV panels are produced in standard sizes that must be incorporated in the renovated facade; custom panels are more expensive. Figure 5 shows BIPVs on the facade of the Solaire high-rise residential building in Battery Park City, New York. PV panels can also be incorporated into roofing systems, as exemplified by the Center for Environmental Sciences at Oberlin College in Ohio (6).

PV panels can be integrated in curtain walls, translucent skylights, shading devices, and roof insulation systems. Some BIPV systems use thin-film technologies to deposit the PV material directly onto glass (e.g., translucent PV for skylights), plastic (e.g., roof shingles), fiber reinforced cement (e.g., roof slates), metal substrate (e.g., standing seam roofing), or textiles (e.g., on park
Emerging Technology Strategies (cont’d)

It is important to remember that PV panels must not be shaded, even partially, for most of the year. The cells in a panel are connected in series; if one cell is shaded, the entire row of cells stops producing. For example, if the shadow of a telephone pole crosses a portion of a PV panel, the entire panel will stop functioning, not just the cells in shade.

- **Wind Turbines** - Wind resources are characterized by wind-power density classes, ranging from class 1 (the lowest) to class 7 (the highest). The Philadelphia area is graded as class 2 with an annual average wind speed of almost 10 miles per hour at a height of 33 feet. Calculations, and possibly on-site monitoring, are necessary to verify that a wind turbine is economically feasible under these conditions.

**Turbine types** - Modern wind turbines fall into two basic groups: the more common horizontal-axis turbines (similar to farm windmills that pump water (7)) and vertical-axis turbines (that resemble an eggbeater (8)). Wind turbines range from small 0.025 kW to multi-megawatt giants. Individual structures (e.g., buildings, park kiosks) are usually equipped with small wind machines that have rotors from 3 to 50 feet in diameter and heights of 50 to 120 feet.

- **Mounting, Output and Cost** - The minimum mounting height depends on the turbine diameter, but more energy is generated by high-mounted turbines. The annual power production of a 10kW wind turbine mounted on a 60-foot tower could be about 83% of the power production of the same wind turbine mounted on a 90-foot tower.

Larger wind turbines are more cost-effective. For example, the installed cost for a 100kW turbine could be approximately $3,000/kW, while a 10kW turbine could be $8,000/kW.

**Environmental impacts** - Slower-rotating wind turbines are less noisy than those that rotate rapidly. This is a consideration for turbines mounted near buildings. The effect on wildlife may be of concern; Audubon Bird Migration Maps should be analyzed for possible interference with migratory paths. Some studies have suggested that birds learn to avoid wind turbines, and that glass office towers are a greater hazard to birds than wind turbines. No definitive conclusions can yet be drawn.

- **Fuel Cells** - Fuel cell technology combines hydrogen and oxygen within an electrochemical process that produces electricity. Byproducts, water and heat, are released as hot water or steam. If this heat can be used at all times during the entire year, the fuel cell efficiency is in the range of 40 - 60% or higher, compared with about 30 - 35% for large fossil-fuels power plants.

**Advantages and Applications** - Because fuel cells are located at a user’s site, they don’t suffer electric line distribution losses. Other advantages of fuel cells include silent operation and no need for a flue. Fuel cells are most effective in buildings that require heat year-round, such as hospitals, prisons, laundries, and zoos. Fuel cells could be used in other building types too (e.g. offices, residences), when coupled perhaps with absorption cooling. Another application is as backup generators — replacing the noise, vibration, and pollution of conventional generators.

**Size and Cost** - Commercially-available fuel cells are currently produced in 200 kW size, but smaller cells, down to 4 kW are under development. For now the price of fuel cells is high (about $6,000 - $8,000/kW), and long-term maintenance expensive ($100,000 - $200,000 every five to seven years for the 200kw cells); however, the future pricing of fuel cells is expected to decrease by about 50% in the next few years.

**WATER-USE REDUCTION**

Water-saving techniques for plumbing fixtures (toilets, urinals, lavatories, showers) can move very fast from a pioneering state to commonplace practice. As the time of this writing, several methods are starting to emerge in the U.S.:

- **Composting toilets** use no water and discharge no effluent to the sewer. They are relatively expensive and need to be located in reasonably close proximity to a composting area. The compost needs to be monitored to avoid health hazards.

- **Vacuum-assisted toilets** operate on the same principle as airplane toilets. They use very little water, but for now are fairly noisy and require additional maintenance.
Emerging Technology Strategies (cont’d)

- **Dual-flush toilets** allow users two flush options: 0.8/gallons per flush (gpf) for liquid waste, and 1.6 gpf for solid waste.

  Manufacturers estimate that up to 40% water savings can be realized annually versus standard single-flush toilets. Most of the current dual-flush products are floor-mounted and are primarily intended for residential or light-duty commercial applications. Some wall-mounted models are available, however, access to the in-wall tank is required. Costs for dual-flush toilets are similar to standard single-flush models.

**WASTEWATER TREATMENT**

Municipal wastewater plants are expensive to build and operate. Load reduction can be accomplished by providing on-site facilities for cleaning the non-sewer water from lavatories and showers (gray water). Other onsite treatment systems take black water – water from all sources, including toilets – and purify it to an almost drinkable quality. In both cases the cleaned water is reused for irrigation, for toilet and urinal flushing, or for cooling towers (currently approvals for these treatments are required in Philadelphia).

- **Benefits**

  Users of emerging technologies play a pioneering role. The benefits accrue to society as much as to the building.

**Life-Cycle Assessment**

Life-cycle economics and grants/incentives form a critical part of the funding of emerging technologies. A short-term payback approach cannot be used to justify most of these technologies.

- **Process** - Gray water is usually filtered and chemically-treated in enclosed tanks. Black water can be treated entirely in enclosed tanks, or can have some of the treatment occur in exposed (and sometimes transparent) tanks that harbor plants, algae, and even fish. This latter approach is called a solar aquatics system (SAS).

  In SAS, a combination of plants, microbes and animals are used to break down the waste and absorb its nutrients, a process that mimics natural systems such as wetlands. SAS are contained in greenhouses; this visibility makes them useful for educational purposes as well (9).

- **Economics** - At first sight it may appear that gray-water systems are more economically feasible than black water, because the treatment of gray-water is less demanding. But gray-water systems require one set of wastewater plumbing lines for lavatories and showers and another one for toilets and urinals. In large buildings, the cost for an additional set of wastewater risers and mains, required for gray-water systems, can be higher than the cost required for a black water treatment plant.

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