

PROFESSIONAL PAPER

ENERGY EFFICIENT WINDOW RETROFITS IN HISTORIC FACILITIES

**Submitted by
Kent Hendricks
Department of Construction Management**

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For Degree of Master of Science
Colorado State University
Fort Collins, Colorado
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Glossary

Awning: a roof-like cover extending over or in front of a place (as over the deck or in front of a door or window) as a shelter or to provide shade.

Blind: something to hinder sight or keep out light such as a window shutter, a roller window shade or Venetian blind.

Caulk: to stop up and make tight against leakage the cracks in a window frame using soft putty materials that are applied in a thin strip along the seams of the frame.

Drape: to cover or adorn with or as if with folds of cloth or other materials to limit the passage of light and control the transfer of heat.

Energy Savings Performance Contract (ESPC): a contract that provides for the performance of services for the design, acquisition, financing, installation, testing, operation, and where appropriate, maintenance and repair, of an identified energy or water conservation measure or series of measures at one or more locations. Such contracts shall provide that the contractor must incur costs of implementing energy savings measures, including at least the cost incurred in making energy audits, acquiring and installing equipment, and training personnel in exchange for a predetermined share of the value of the energy savings directly resulting from implementation of such measures during the term of the contract. Payment to the contractor is contingent upon realizing a guaranteed stream of future energy and cost savings. All additional savings will accrue to the client.

ENERGY STAR® Program: a government/industry partnership that offers businesses and consumers energy-efficient solutions, making it easy to save money while protecting the environment for future generations. In 1992 the US Environmental Protection Agency (EPA) introduced ENERGY STAR as a voluntary labeling program designed to identify and promote

energy-efficient products to reduce greenhouse gas emissions. In 1996, EPA partnered with the US Department of Energy for particular product categories. The ENERGY STAR label is now on major appliances, office equipment, lighting, home electronics, and more. EPA has also extended the label to cover new homes and commercial and industrial buildings. ENERGY STAR has successfully delivered energy and cost savings across the country, saving businesses, organizations, and consumers about \$12 billion in 2005 alone.

GigaJoule: a joule is the unit of work or energy equal to the work done by a force of one newton acting through a distance of one meter. GigaJoule = 1 billion joules.

Greenhouse Gases: petroleum-based fuel emissions that contribute to the warming of the surface and lower atmosphere of the earth caused by conversion of solar radiation into heat in a process involving selective transmission of short wave solar radiation by the atmosphere, its absorption by the planet's surface, and reradiation as infrared which is absorbed and partly reradiated back to the surface by atmospheric gases.

Leadership in Energy and Environmental Design (LEED): Green Building Rating System is a voluntary, consensus-based national standard for developing high-performance, sustainable buildings. LEED provides a complete framework for assessing building performance and meeting sustainability goals. Based on well-founded scientific standards, LEED emphasizes state of the art strategies for sustainable site development, water savings, energy efficiency, materials selection and indoor environmental quality. LEED recognizes achievements and promotes expertise in green building through a comprehensive system offering project certification, professional accreditation, training and practical resources. LEED standards include: new commercial construction and major renovation projects, existing building

operations, commercial interiors projects, core and shell projects, homes, and neighborhood development.

Life-Cycle Costs: sum of the present values of investment costs, capital costs, installation costs, energy costs, operating costs, maintenance costs, and disposal costs, over the lifetime of the project, product, or measure.

Life-Cycle Cost-Effective: life-cycle costs of a product, project, or measure are estimated to be equal to or less than the base case (i.e., current or standard practice or product).

Long-Wave Heat: The sun's energy is short-wave radiation which passes through the window and is absorbed by carpet, furniture, etc. The energy is then transformed into long-wave radiation. The long-wave radiation wants to flow from warm to cool. These sun-warmed objects then re-radiate long-wave rays of invisible infrared heat. Likewise, long-wave radiant heat is provided within the home from other sources such as heating systems, fireplaces, lightbulbs, appliances and even our warm bodies.

Low-Emissivity (Low-E): Emissivity is a measure of how much a glass surface transfers radiant heat. Low-E glass is clear glass with a thin, transparent metal-oxide coating which helps block the transfer of radiant heat. This results in a window that can keep any home, in any location, warmer in winter and cooler in summer.

Million Solar Roofs Initiative: Facilitates the installation of solar energy systems on one million U.S. buildings by 2010. Focuses on two types of solar technology: solar electric systems (or photovoltaics) that produce electricity from sunlight and solar thermal systems that produce heat for domestic hot water, space heating, or heating swimming pools. The U.S. Department of Energy, through its Regional Offices, focuses its efforts on national, state and local partnerships, to remove market barriers to solar energy use and develop and strengthen local demand for solar

energy products and applications. Particular products are not prescribed, nor is funding provided to design, purchase or install solar energy systems. Instead, the initiative brings together the capabilities of the Federal government with key national businesses and organizations and focuses them on building a strong market for solar energy applications on buildings.

National Historic Preservation Act of 1966 (NHPA): provides for preservation of significant historical features (buildings, objects and sites) through a grant-in-aid program to the States. It established a National Register of Historic Places and a program of matching grants under the existing National Trust for Historic Preservation. The Act established an Advisory Council on Historic Preservation, which was made a permanent independent agency, and also created the Historic Preservation Fund. Federal agencies are directed to take into account the effects of their actions on items or sites listed or eligible for listing in the National Register.

National Register of Historic Places: the Nation's official list of cultural resources worthy of preservation. Authorized under the National Historic Preservation Act of 1966, the National Register is part of a national program to coordinate and support public and private efforts to identify, evaluate, and protect our historic and archeological resources. Properties listed in the Register include districts, sites, buildings, structures, and objects that are significant in American history, architecture, archeology, engineering, and culture. National Register properties are distinguished by having been documented and evaluated according to uniform standards. The National Register is administered by the National Park Service, which is part of the U.S. Department of the Interior.

Overhang: portion of the roof of a building that projects over the window to providing shade.

R-Value: a measure of resistance to the flow of heat through a given thickness of a material (as insulation) with higher numbers indicating better insulating properties.

Renewable Energy Technology: technologies that use renewable energy produced by solar, wind, geothermal, or biomass power to provide light, heat, cooling, or mechanical or electrical energy for use in facilities or other activities. The term also means the use of integrated whole-building designs that rely upon renewable energy resources, including passive solar design.

Secretary of Interior's Standards for Historic Preservation: basic historic preservation guidance for identifying, retaining, and preserving the form and details of historic properties. This philosophy is implemented through a hierarchy that emphasizes maintaining and protecting first, repairing second, and replacing only when maintenance or repairs are not feasible or cost-effective. The Standards also include guidance for replicating or reconstructing missing elements and adding to or altering historic properties.

Shutter: a usually movable cover or screen for a window or door that limits the passage of light and helps to control flow of heat gain or loss.

Source Energy: energy that is used at a site and consumed in producing and in delivering energy to a site, including, but not limited to, power generation, transmission, and distribution losses, and that is used to perform a specific function, such as space conditioning, lighting or water heating.

Utility Energy Service Contract (UESC): a contract that provides for the performance of demand-side management services provided by a utility to improve the efficiency of use of the commodity (electricity, gas, etc.) being distributed, such as energy efficiency and renewable energy project auditing, financing, design, installation, operation, maintenance, and monitoring of an identified energy or water conservation measure or series of measures at one or more

locations. Such contracts shall provide that the contractor must incur costs of implementing energy savings measures, including at least the cost incurred in making energy audits, acquiring and installing equipment, and training personnel in exchange for a predetermined share of the value of the energy savings directly resulting from implementation of such measures during the term of the contract. Payment to the contractor is contingent upon realizing a guaranteed stream of future energy and cost savings. All additional savings will accrue to the client.

Abstract

Owing to an ever increasing emphasis on reducing energy usage in buildings, the older windows found in historic buildings are often in danger of being replaced during rehabilitation projects. These older windows are replaced with more energy efficient models that often do not match the existing historic appearance. It is well documented that windows are poor insulators causing increased heating or cooling load, depending on the weather conditions, and thus are the usual targets when trying to improve a building's thermal performance. This paper discusses the somewhat dissimilar goals of the federal government's energy management program and its historic preservation policies. The main purpose of the paper is to suggest and recommend alternative methods of improving the energy efficiency of existing historic windows while at the same time maintaining the significance and character of the window units. Several case studies are examined that support the repair and rehabilitation of windows to both retain historic materials and to also reduce energy consumption. Many owners and architects, impatient with the time consuming demands of preservation, forfeit valuable historic resources in favor of the expediency of window replacement. In most cases the alternative methods produce energy savings equal to or greater than the savings gained by replacing windows with newer models, at a lower cost.

Introduction

With the dwindling supply of petroleum-based energy resources and new energy efficiency demands placed on both newly constructed and existing buildings, many owners of historic buildings are assessing the ability of these buildings to conserve energy with an eye to improving thermal performance (Henck, 1990). Restorations or rehabilitations of historic buildings commonly explore the potential for making changes to the exterior building shell, heating and cooling systems, and other energy consuming components in order to improve energy efficiency. Typical building elements considered for replacement or modification can include lighting fixtures, heating systems, plumbing fixtures, insulation, roofing and siding materials, and windows.

Often a competing concern with energy reduction is the Secretary of Interior's Standards for Historic Preservation¹ requiring that architects strive to identify, retain, and preserve the functional and decorative features of historic buildings, and wherever possible, protect and maintain existing building fabric (Ivy, 1992). Barista (2001) states that during a time when interest in the restoration of historic buildings is at an all-time high, strict preservation guidelines make energy reduction projects more challenging for building teams and owners. Preserving historic integrity while at the same time modernizing the building for energy efficiency, client use, and meeting new fire and life safety codes, can be the most challenging aspect for owners and contractors (National Park Service, 1978). As the owner of an aging stock of buildings and facilities, while also being the largest single consumer of energy in the nation, the federal government constantly battles the competing interests of energy efficiency and historic preservation of its buildings (EERE, 2005).

¹ See Glossary for definition or explanation.

This paper will focus on one specific element that poses certain challenges for federal government agencies such as the General Services Administration (GSA) and the Department of Defense (DOD) related to improving energy efficiency while preserving historic character: the window. Windows are thermal holes on the perimeter of all buildings. An average building may lose 30 percent of its heat or air-conditioning energy through its windows (Fisette, 1998, p. 68). First the energy conservation programs and historic preservation policies of the federal government will be reviewed for purposes of comparison later in the paper. Then the aspects of historic wooden and metal windows repairs will be examined. Different heating and cooling properties and energy loss principles will be discussed. Thermal property improvement methods of historic windows will be covered and compared through four different case studies. Finally, the overriding themes presented in the paper will be summarized and recommendations made for improvements in project and construction management practices, as well as for areas of future research.

Windows are an area of emphasis and concern in nearly every rehabilitation project. Typically, windows are visibly deteriorated because of the lack of routine maintenance, such as painting and caulking. If a building's use changes, even well-maintained windows will require rehabilitation treatment. When energy efficiency is a factor and lead time in ordering materials is estimated, an owner may initially conclude that replacement windows are a necessity (New York Landmarks Conservatory, 1992). But there are good reasons for taking a closer look at repairing existing windows. Recycling the existing windows may meet a project's requirements and offer a less expensive solution with the added benefit of preserving irreplaceable original design elements of the building (New York Landmarks Conservatory, 1992).

It has been said that the windows are the eyes of a building (Barista, 2001). Certainly windows are an element, which if replaced or altered unsympathetically, will do the most to alter the character of a building (National Park Service, 1978). The design, craftsmanship, or other qualities of particular windows may make them worthy of preservation. Henck (1990) points out the self-evident qualities of ornamental windows, but it can be equally true for warehouses or factories where the windows may be the most dominant visual element of an otherwise plain building.

Federal Energy Management Program

Executive Order 13123

The federal government is the nation's single largest energy consumer as well as waster. The over 500,000 federal buildings and facilities consume approximately 1.4 percent of all the energy used in the nation (NREL, 2005). The federal government has a proven over time that it is willing to spend large amounts of time and money to decrease energy consumption. Between 1977 and 1989, the federal and state governments spent over \$2.4 billion to weatherize low-income residences through a variety of programs (Cohen, Goldman, & Harris, 1991). Executive Order 13123, Section 101 states

The Federal Government, as the Nation's largest energy consumer, shall significantly improve its energy management in order to save taxpayer dollars and reduce emissions that contribute to air pollution and global climate change. With more than 500,000 buildings, the Federal Government can lead the Nation in energy efficient building design, construction, and operation. As a major consumer that spends \$200 billion annually on products and services, the Federal Government can promote energy efficiency, water conservation, and the use of renewable energy products, and help foster markets for emerging technologies. (1999, ¶1)

Specific energy reduction goals are highlighted within Executive Order 13123, tasking each government agency to reduce energy consumption per gross square foot of its facilities by 30 percent by 2005 and 35 percent by 2010 relative to 1985 energy usage levels (EERE, 2005, ¶3).

In addition to many of the energy reduction methods cited, the Executive Order, titled Greening the Government through Energy Efficiency, also emphasizes goals for renewable energy sources and sustainable building design and materials. Section 201 states that agencies shall reduce their greenhouse gas emissions attributed to facility energy use by 30 percent by 2010 compared to 1990 (EERE, 2005, ¶2). Per Section 204 agencies shall strive to expand the use of renewable energy within their facilities and activities by implementing renewable energy projects and by purchasing electricity from renewable energy sources (NREL, 2005). Specifically this renewable energy section states that 2.5 percent of facilities' electricity consumption will come from new renewable energy sources by 2005 (EERE, 2005, ¶5). In support of the Million Solar Roofs initiative, the federal government shall strive to install 2,000 solar energy systems at federal facilities by the end of 2000, and 20,000 solar energy systems at federal facilities by 2010 (EERE, 2005, ¶5). Section 205 states that each agency shall reduce the use of petroleum within its facilities. Agencies may accomplish this reduction by switching to a less greenhouse gas-intensive, non-petroleum energy source, such as natural gas or renewable energy sources. Per Section 206 agencies shall undertake life-cycle cost-effective projects in which source energy decreases, even if total site energy usage increases (NREL, 2005). Section 403 states that federal facilities shall use combined cooling, heat and power systems, whenever life-cycle cost effective, to achieve their energy reduction goals (NREL, 2005).

The primary methods utilized by the federal government to achieve the required energy savings have been Energy Savings Performance Contracts (ESPC) and Utility Energy Service Contracts (UESC) (EERE, 2005). Although energy efficient investments save money over time, federal appropriations do not provide adequate funding to meet the prescribed targets. Thus Congress has authorized federal agencies to utilize the private sector for investment capital via

the ESPC and UESC (NREL, 2005). An energy service company will typically finance and help implement energy saving projects through an ESPC and then in turn paid out of the resulting stream of energy bill savings. Many electric and gas utilities also offer financing for energy efficient projects through the UESC vehicle as part of their demand-side management (DSM) programs (EERE, 2005). DSM programs are implemented by utilities to help defer the need for building new power generation facilities. As with ESPCs, utilities are paid under UESCs from utility bill savings due to the projects. Both ESPCs and UESCs allow federal agencies to address government energy goals without paying the cost up front (EERE, 2005).

General Services Administration Implementation

Each agency of the federal government must comply with Executive Order 13123 and in turn develop their agency specific energy reduction plan and goals. The GSA constructs, maintains, and manages facilities for most of the civilian government employees (GSA, 2005). GSA is the nation's largest public real estate organization maintaining more than 335 million square feet of workspace for more than one million federal employees in over 2,100 American communities (GSA, 2005, ¶5). Examples of GSA facilities include the Internal Revenue Service, Environmental Protection Agency, and Federal Court System buildings to name just a few. GSA annually develops an implementation plan to ensure all the energy management strategies identified in Executive Order 13123 are being pursued. Energy reduction and utility cost reduction goals are tracked as part of GSA's performance evaluation to the President and results are reported to GSA senior management on a quarterly basis (GSA, 2005).

Since 1985, GSA has reduced energy usage in government facilities from 83,682 British thermal units (BTU) per gross square foot (GSF) to 66,174 BTU's per GSF (GSA, 2005, ¶8). This reduction represents a decrease of 20.9 percent compared with the 1985 base year (GSA,

2005, ¶9). The agency achieved most of this reduction by directly investing in energy conservation opportunities with paybacks of 10 years or less. From 1990 through 2002, GSA invested approximately \$316.5 million in energy projects (GSA, 2005, ¶10).

GSA also benchmarks performance with comparable facilities operated and managed in the private sector. The utility benchmark, established by the Building Owners and Management Association, indicates GSA is operating federal facilities 34 percent below comparable commercial facilities for the period ending September 30, 2002 (GSA, 2005, ¶5).

Looking toward the future, GSA requires all new buildings and major repairs or alterations projects for existing buildings to conform to Leadership in Energy and Environmental Design (LEED) Silver requirements. GSA's ultimate goal with the LEED program is to bring new buildings into the government's inventory that are energy efficient, while optimizing the energy performance of the existing building inventory (GSA, 2005).

Contrary to some interpretations, meeting LEED guidelines does not require replacing historic windows (wbdg, 2006). Historic windows can be reused in an energy efficient manner. For example, a traditional single-glazed, double hung window has an R-value of 1, compared to R3 for a new double-glazed, low-emissivity (low-E), double hung window. If the historic wall assembly has an R-value in the teens, taking a window from R1 to R3 will not provide sufficient energy savings to offset the cost of replacement windows and associated waste and therefore does not justify any LEED points (wbdg, 2006).

Department of the Defense Energy Program

Conserving energy had been a top priority for the DOD even prior to the Executive Order 13123, for utility budgetary and environmental reasons. The DOD intends to meet the goals of the Executive Order with a number of the following strategies: life-cycle cost analysis, facility

energy audits, financing mechanisms, energy-efficient products, sustainable building design, industrial facility efficiency improvements, water conservation, and off-grid power generation (DOD implementation plan, 2002). Included within the category of energy-efficient products are lighting fixtures, ballasts, motors, heating and cooling equipment, insulation, and window treatments (NREL, 2005).

As of May 2004, energy consumption in DOD buildings has dropped 22 percent since 1985 due to better energy management (EERE, 2005, ¶4). The Department of the Navy (DON) which constructs and manages all U.S. Navy and U.S. Marine Corps facilities has reduced energy consumption per gross square foot by 27.5 percent through 2004 relative to the 1985 baseline (Department of the Navy, 2004, p. 4). By implementing energy program initiatives, compared to expenditures in 1985, the DON is avoiding more than \$400 million, inflation-adjusted, annually (Department of the Navy, 2004, p. 4).

ENERGY STAR® performance criteria are now included in acquisition requirements for systems and appliances for all renovation and new construction projects for both DOD and GSA (NREL, 2005). For product groups where ENERGY STAR® labels are not yet available, agencies shall select products that are in the upper 25 percent of energy efficiency as designated by the Federal Energy Management Program (EERE, 2005, ¶26). Per Executive Order 13123, the DOD and GSA shall strive to meet the ENERGY STAR® building criteria for energy performance and indoor environmental quality in their eligible facilities to the maximum extent practicable by the end of 2002 (EERE, 2005). Agencies may use ESPCs, UESCs, or other means to conduct evaluations and make improvements to buildings in order to meet the criteria. Buildings that rank in the top 25 percent in energy efficiency relative to comparable commercial and federal buildings will receive the ENERGY STAR® building label (EERE, 2005, ¶29).

The DON energy projects team adopted the Department of Energy's (DOE) Building Life Cycle Costing software as a standard for determining project economics. Sustainable development projects use life cycle costing methodology and follow the whole building design guide (Department of the Navy, 2004). DON has implemented a Sustainable Development Policy in order to reduce the total cost of ownership of facilities, requiring all new construction projects be LEED certifiable (Department of the Navy, 2004).

Federal Government Agency Historic Preservation Guidance

Old buildings, artifacts, and physical pieces of history are preserved for many reasons. Historians have argued for centuries for the need of preservation. Historians typically cite different reasons such as national pride and identity or the need for educational items. Hodges-Fulton (2004) cites the following reasons for preservation: memory, continuity, familiarity, diversity, tangibility, orientation, education, recreation, inspiration, economics, quality of life, frugality, and responsibility. Most people would agree that preservation is important, but are also concerned with the cost and value of preservation. Hodges-Fulton (2004) contends that cultural property has the three major values of emotion, culture, and use. These values help to systematically set overall priorities in deciding proposed interventions, as well as to establish the extent and nature of the individual treatment of a historic property or structure.

GSA Historic Preservation Policy

The National Historic Preservation Act (NHPA) of 1966 is the basic program for the preservation of irreplaceable properties throughout the nation. The NHPA requires federal agencies to protect historic resources and GSA, along with all other federal agencies, is charged with the administration of federally owned or controlled historic resources in a spirit of stewardship for the inspiration and benefit of present and future generations (GSA, 2005). The

Section 106 process of 36 CFR Part 800 requires the review of preservation concerns for all federally funded construction or repair projects involving historic structures (Advisory Council on Historic Preservation, 1994). GSA and all federal government agencies refer to the Secretary of Interior's Standards for Historic Preservation. Executive Order 13006 instructs the federal government to do the following:

- When planning federal facilities, give first consideration to historic properties within historic districts in central cities.
- Consider other developed or undeveloped sites within historic districts if no such property is suitable.
- Subsequent renovation or construction must be architecturally compatible with the surrounding district.

Department of Defense Historic Preservation Policy

The DOD's policy is to integrate the historic preservation requirements of applicable laws with the planning and management of activities in order to minimize expenditures and to encourage practical, economically feasible rehabilitation and adaptive use of significant historical resources (Advisory Council on Historic Preservation, 1994). Historic preservation programs will be integrated into land use plans and other planning activities to reduce adverse effects on significant historic properties. All DOD components shall consult with the state historic preservation officer (SHPO), using the Section 106 process, concerning effects of proposed projects on National Register properties. All properties, including those from the "Cold War" era, shall be evaluated in a manner fully consistent with military mission requirements and using the appropriate criteria to determine eligibility for nomination to the National Register of Historic Places. Eligible properties shall be used for mission purposes to

the maximum extent possible before acquiring, constructing, or leasing other buildings (DOD conservation program, 1996).

The DON is an owner of many historic buildings, structures, districts, and other cultural resources. Protection of these components of the nation's heritage is an essential part of the defense mission (Department of the Navy, 2001). Preservation considerations will be incorporated into routine DON management of historic buildings, structures, sites, districts, and other cultural resources. When functionally appropriate and economically prudent, DON will give preference to the rehabilitation or adaptive use of historic properties over new construction or leasing (Department of the Navy, 2001).

All branches of the DOD echo similar historic preservation mandates and policy statements. The Air Force's Cultural Management Program states that all historical properties will be identified, managed, and maintained in a spirit of stewardship for the benefit of this and future generations of Americans (Air Force cultural resources management program, 2004). Each Army installation commander shall administer, manage, and treat historic properties in accordance with the NHPA (Army cultural resources management, 1998). The Army will identify, evaluate, and take into account the effects of all undertakings on historic properties in accordance with the procedures set forth in Section 106 of the NHPA (Army cultural resources management, 1998).

Repair of Historic Windows

Historic Significance

Evaluating the architectural or historical significance of windows is the first step in planning for window treatments. As a part of this evaluation, one must consider four basic window functions: admitting light to the interior spaces, providing fresh air and ventilation to the

interior, providing a visual link to the outside world, and enhancing the appearance of a building (National Park Service, 1981). Windows should be considered significant to a building if they: a) are original, b) reflect the original design intent for the building, c) reflect period or regional styles or building practices, d) reflect changes to the building resulting from major periods or events, or e) are examples of exceptional craftsmanship or design (National Park Service, 1981).

If the overall appearance of the building would be changed noticeably when the windows were removed or radically altered, then the windows are probably significant. In the case of significant windows, replacement in kind is essential in order to maintain the historic character of the building (National Park Service, 1984). See Figure 1 below for examples of improper window replacement resulting in a loss of the buildings' historical character. However, for less



Figure 1. Improper window replacements (National Park Service, 1978)

significant windows, replacement with compatible new windows may be acceptable. If the windows are significant, they will reflect the original design intent of the architect, and reflect the period and regional style (Hodges-Fulton, 2004). The scale, design, proportion and detailing of windows in relation to the building are other factors to consider when evaluating the historic significance of a window (National Park Service, 1984). The key to successful planning for

window treatments is a careful evaluation of existing physical conditions on a window-by-window basis.

Wooden Window Repair

Wooden sash windows often appear seriously deteriorated, but may in fact only need a good cleaning. Deterioration of wood windows begins at the time of installation. Moisture is the primary contributing factor in wooden window deterioration. Water penetration is the most serious cause of deterioration, causing structural damage and affecting the overall appearance of the window (New York Landmarks Conservancy, 1992). One clue to the location of areas of excessive moisture is the condition of the paint; therefore, each window should be examined for areas of paint failure (National Park Service, 1981). Figure 2 below shows an example of deterioration caused by water saturated wood. After noting areas of paint failure, the next step is to inspect the condition of the wood, particularly at the points identified during the paint examination.

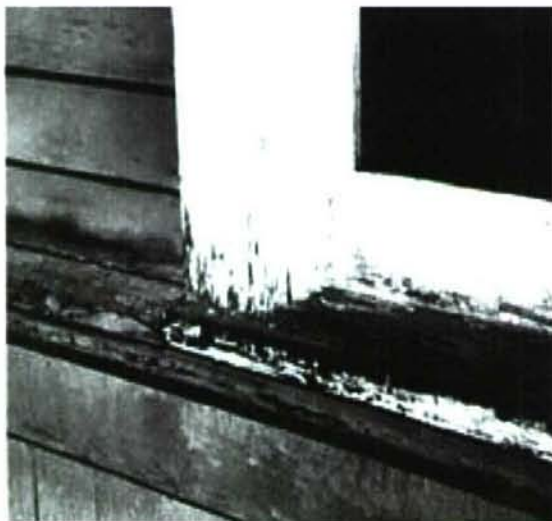


Figure 2. Deteriorated wood sill and sash (National Park Service, 1981)

Repair activities fall into three broad categories: routine maintenance procedures, structural stabilization, and parts replacement. The routine maintenance required to upgrade a

window to acceptable condition normally includes some degree of interior and exterior paint removal, removal and repair of sash and possibly re-glazing, repairs to the frame, and repainting (National Park Service, 1978).

Many windows will show some additional degree of physical deterioration, but even badly damaged windows can be repaired using simple processes. Wood which is split, checked or shows signs of rot, can be repaired by drying, treating with a fungicide, waterproofing, and filling cracks and holes with putty, sanding and then repainting (National Park Service, 1981). Wood may also be strengthened and stabilized by consolidation, using semi-rigid epoxies which saturate the porous decayed wood and then harden to restore near original strength.

Moisture laden wood creates an environment for fungi growth. Fungi are threadlike plants that grow within the wood by feeding on the wood cell walls. Fungi generally develop when moisture content exceeds 20 percent and temperatures are below 115 degrees Fahrenheit (New York Landmarks Conservancy, 1992). When fungi are present and active, wood is considered to be rotting.

When parts of the frame or sash are so badly deteriorated that they cannot be stabilized there are methods which permit the retention of some of the existing or original fabric. These methods involve replacing the deteriorated parts with new matching pieces, or splicing new wood into existing members. Henck (1990) reports there are companies which still manufacture high quality wooden sash which would duplicate most historic sash.

There is a point when the condition of a window may clearly indicate replacement. The decision process for selecting replacement windows should not begin with a survey of contemporary window products which are available as replacements, but should begin with a look at the windows which are being replaced. Check building supply firms, local woodworking

mills, carpenters, preservation oriented magazines, or catalogs or suppliers of old building materials for product information. Manufacturers such as Pella, Marvin, Hope, Camden, Graham, Weathershield, and others produce true multi-paned windows that can match existing exterior profiles, and replicate unusually shaped windows (Ivy, 1992). Another option that many manufacturers offer is made with a single, large sealed glass unit with muntins glued to the inside and outside surfaces, while a grid is placed in the middle of one large insulated unit, giving the visual effect of divided lights (Carmody, Selkowitz, & Heschong, 1996). Local historical associations and state historic preservation offices may be good sources of information on products which have been used successfully in preservation projects (Henck, 1990). Energy efficiency should be considered as one of the factors for replacement, but should not be the dominant issue. Energy conservation is no excuse for the wholesale destruction of historic windows which can be made thermally efficient by historically and aesthetically acceptable means (National Park Service, 1981).

Metal Window Repair

Windows are among the most vulnerable features of historic buildings undergoing rehabilitation. This is especially the case with rolled steel windows, which are often mistakenly not deemed worthy of preservation in the conversion of old buildings to new uses (National Park Service, 1984). Around 1890, technology advances permitted the mass production of rolled steel windows, making metal windows cost competitive with conventional wooden windows (National Park Service, 1984). Haynes (1987) cites the devastating fires in that era, leading to tougher fire codes, as also contributing to the new popularity of metal windows.

Corrosion, principally rusting in the case of steel windows, is the controlling factor in window repair; therefore, the evaluator should first test for its presence. Unlike wood

deterioration, metal corrosion generally results in a slight increase in the material's mass while at the same time making the metal fragile (New York Landmarks Conservancy, 1992). Metal corrosion occurs whenever there is a failure of the protective paint or other coating and the metal is exposed to oxygen and rainwater on a prolonged basis. Figure 3 below shows corroded metal window frame that can be repaired in place. The presence of bowing or misalignment of metal



Figure 3. Corroded steel window frame (National Park Service, 1984)

sections, the amount of glass needing replacement, and the condition of the masonry or concrete surrounds must be assessed in the evaluation process (National Park Service, 1984). These are key factors in determining whether or not the windows can be repaired in place. Since moisture is the primary cause of corrosion in steel windows, it is essential that excess moisture be eliminated and that the building be made as weather-tight as possible before any other work is undertaken (National Park Service, 1984). Moisture can accumulate from cracks in the masonry, from spalling mortar, from leaking gutters, from air conditioning condensation runoff, and from poorly ventilated interior spaces (National Park Service, 1978).

If it is determined that the windows are in basically sound condition, only light rust will need to be removed, using manual and mechanical abrasion or the application of chemicals.

Bent or bowed metal sections may be the result of damage to the window through an impact or corrosive expansion (National Park Service, 1984). If the distortion is not too great, it may be possible to re-align the metal sections without removing the window to a metal fabricator's shop.

Repair of historic windows is always preferred within a rehabilitation project.

Replacement should be considered only as a last resort. However, when the extent of deterioration or the unavailability of replacement sections renders repair impossible, replacement of the entire window may be justified. See Figure 4 below for an example of improper replacement of historic metal windows. Windows manufactured from other materials generally cannot match the thin profiles of the rolled steel sections. Aluminum, which is three times weaker than steel, and wooden or vinyl replacement windows generally are not fabricated in the industrial style, nor can they reproduce the thin profiles of the rolled steel sections, and consequently are generally not acceptable replacements (National Park Service, 1978). A number of metal window manufacturing companies produce rolled steel windows and most can reproduce the historic configuration (National Park Service, 1984). Additionally, some manufacturers still carry the standard pre-World War II multi-light windows using the traditional 12 inch by 18 inch or 14 inch by 20 inch glass sizes (National Park Service, 1984, p. 13).

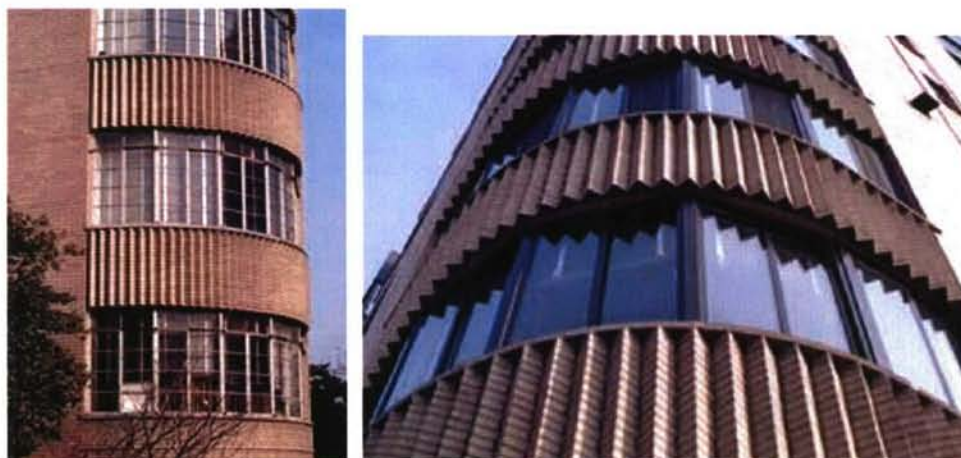


Figure 4. Improper replacement of metal windows (National Park Service, 1984)

Improving Energy Efficiency of Historic Windows

Determining the nature and extent of a window's energy loss is a prerequisite in assessing its rehabilitation potential and possible methods to be used (National Park Service, 1978). It has been estimated that windows in typical homes in the northern half of the U.S. are responsible for 15 to 35 percent of the building's total heat loss during the winter (New York Landmarks Conservancy 1992, p. 81). In the US, over three percent of the total energy consumption is lost through window openings, in Sweden with a colder climate, this figure is seven percent, and in Great Britain is six percent for residential buildings alone (Menzies & Wherrett, 2005, p. 249).

Many historic buildings have energy saving physical features and devices that contribute to good thermal performance. Studies by the Energy Research and Development Administration show that the buildings with the poorest energy efficiency are actually those built between 1940 and 1975 (National Park Service, 1978). Older buildings were found to use less energy for heating and cooling and hence probably require fewer weatherization improvements (National Park Service, 1978). Historic buildings usually use less energy because they were built with a well-developed sense of physical comfort and because they maximized the natural sources of heating, lighting and ventilation. The most obvious inherent energy saving characteristic was the use of operable windows to provide natural ventilation and light. To minimize the heat gain or loss from windows, historic buildings often include interior or exterior shutters, interior venetian blinds, curtains and drapes, or exterior awnings (Haynes, 1987). Windows lose and gain heat by conduction, radiation, convection, and air infiltration. Some of these qualities can be improved by a single improvement, but a combination of methods may be necessary to improve the overall thermal properties of particular historic windows. Each heat transfer method is depicted in Figure 5.

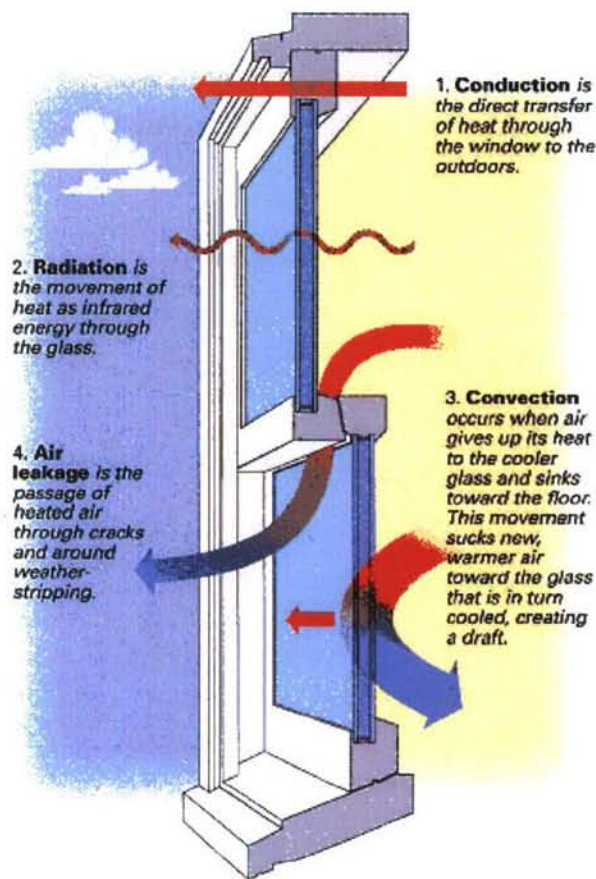


Figure 5. Window heat transfer methods (Fisette, 1998)

Heat flow from the warmer side to the colder side of a window and frame is a complex interaction of all the heat transfer mechanisms described above. The ability of a window assembly to resist heat transfer is referred to as its insulating value (Carmody et al., 1996). Heat flows from warmer to cooler bodies, thus from inside to outside in winter, and reverses direction in the summer months. The R-value is a resistance measure of the insulating qualities of the materials of which a wall or window is made. The higher the R-value the less heat is transferred or lost through a surface in winter. The material thickness of a surface as well as air space between surfaces and insulating materials inserted into an air space contribute to the R-value (Carmody, et al, 1996). Thermal blankets and blown in fiberglass insulation is often added to walls and ceilings to increase the R-value.

From a historic character perspective, inappropriate building alterations, such as the wholesale removal of historic windows, should be avoided. Another potential problem area is to assure that retrofitting measures do not create moisture related deterioration problems (Barista, 2001). Finally contractors and owners should avoid use of those materials that are chemically or physically incompatible with existing materials, or that are improperly installed.

How can energy reductions be achieved while at the same time the maximum amount of historic window fabric retained and preserved? The goals of the most successful rehabilitation strategies listed by the New York Landmarks Conservancy (1992), include measures that:

- Preserve the architectural character of the window
- Improve the insulating performance of the window
- Help maintain the window over time
- Cost effective

Each project and situation is unique and will incorporate different solutions, but compromise is frequently the ultimate answer to this question (Padjen, 1995). A small-scale historic structure may require more preservation vigilance than a 30-story building because of the relative ease in noticing significant changes to historic character (Ivy, 1992). Even within the scope of repairing and replacing windows, there may not be one single overriding solution to the treatment method employed on windows (Padjen, 1995). For example, the lower floor windows of the high rise might be repaired, mid-level windows replaced, and top-floor windows replicated. The windows on the side elevations may be handled entirely differently than those on primary facades (Ivy, 1992).

Conduction

Conductive heat loss is caused by heat flowing out of a building through the exterior envelope (New York Landmarks Conservancy, 1992). Conduction is the movement of heat through a solid material. If you were to touch a hot skillet, you feel heat conducted from the stove through the pan. Heat flows through a window much the same way. With a less conductive material, you impede heat flow. The less resistance to heat flow, or R-value, a window has the greater will be the heat loss due to conduction. Windows with low R-values are a prime source of conductive heat loss. Other factors that contribute to conductive heat loss in windows are: single glazing, conductive metal frame and sash members, and water-soaked wood frame or sash.

Metal has a very low R-value, and if metal windows are constructed without a thermal break a direct path for heat to flow out of a building is established. To resist this heat exodus, a plastic thermal break can be introduced to separate the metal's exterior and interior faces (National Park Service, 1984). When no thermal break exists, condensation on the inside will indicate direct heat transfer. Wood is a good insulator with a relatively high R-value. But water-soaked wooden frames and sashes have a much reduced R-value due to the increased conductivity of moisture (New York Landmarks Conservancy, 1992).

By adding an additional layer of glazing material to the sash, an insulating layer of air can be created. The thickness of the sash and muntins must be wide enough to accept an added glazing layer. Air space between glass layers is a significant factor in increasing R-values. The type of air trapped between the panes of glass also affects the R-value. Low-conductance gas such as argon between panes of glass significantly improves R-values (Fisette, 1998). By adding

a second layer of glazing and an air space, the R-value can be increased by more than 44 percent, thus reducing conductive heat loss (National Park Service, 1978).

Radiation

Radiant transfer is the movement of heat as long-wave heat energy from a warmer body to a cooler body (Fisette, 1998). Radiant transfer is the warm feeling on your face when you stand near a woodstove. Conversely, your face feels cool when it radiates its heat to a cold sheet of window glass. Heat loss and more prominently heat gain results from radiation. Since windows contain transparent materials, heat can be radiated through them, in or out of a building. Clear glass absorbs heat and reradiates it outdoors. Radiation becomes an even greater problem in a building with air conditioning. Heat from direct sunlight shining through windows adds considerably to the cooling load. Heat radiated out of a building at night or on winter days is a less considerable problem, but still worth noting, especially in colder climates (National Park Service, 1978).

The primary cause of radiation losses or gains is a lack of shading for the windows. Window treatments such as awnings, blinds, shutters, drapes, and overhangs are the main methods to reduce radiation losses or gains (New York Landmarks Conservancy, 1992). Shading the window opening to reduce solar gain should be considered primarily for south and possibly east and west facing windows. Radiant heat loss through windows can be greatly reduced by placing low-E coatings on glass that reflect specific wavelengths of energy (Fisette, 1998). In the same way, low-E coatings keep the summer heat out.

Convection

Convection is another way heat moves through windows. In a cold climate, heated indoor air rubs against the interior surface of window glass. A cold interior glazing surface chills

the air adjacent to it. The air cools, becomes denser and drops toward the floor. As the stream of air drops, warm air rushes in to take its place at the glass surface. The cycle, a convective loop, is self-perpetuating (National Park Service, 1984). Convection affects the heat transfer in three places in the assembly: the inside glazing surface, outside glazing surface, and the air space between the inside and outside glazing (Carmody et al., 1996).

People typically perceive this cold air flow as a draft caused by leaky windows, and are tempted to plug any holes they can find, rather than remedy the situation correctly with a better window glazing that provides a warmer glass surface (Carmody et al., 1996). This air movement often prompts an owner to turn up the heat. Unfortunately, each 1°F increase in thermostat setting increases energy use 2 percent (Fisette, 1998, p. 69). Multiple panes of glass separated by low-conductance gas fillings and warm edge spacers, combined with thermally resistant frames, raise inboard glass temperatures, slow convection and improve comfort.

Air Infiltration

Haynes (1987) stated that substantial heat loss occurs because cold outside air infiltrates the building through loose windows, doors, and cracks in the outside shell of the building. Air leakage siphons about half of an average home's heating and cooling energy to the outdoors, and leakage through windows is responsible for much of this loss (Fisette, 1998). Reducing air infiltration should be the first priority of a preservation retrofitting plan (Haynes, 1987). Hinged windows such as casements and awnings usually clamp more tightly against weatherstripping than do double-hung windows. How well the individual pieces of the window unit are joined together also affects air leakage. Glass-to-frame, frame-to-frame and sash-to-frame connections must be tight to prevent air infiltration. Adding weatherstripping to doors and windows, and caulking of open cracks and joints will substantially reduce this infiltration. Care should be

taken not to reduce infiltration to the point where the building is completely sealed and moisture migration is prevented. Without some infiltration, condensation problems could occur throughout the building (National Park Service, 1978).

Thermal Comfort

The thermal comfort derived due to windows is an important but difficult to quantify factor. In winter, thermal comfort near a window is provided by minimizing cold air leakage, and by maximizing the temperature of the glass itself. A window with lower glass temperature feels colder because more heat is radiated from a person's body to the window (Carmody et al., 1996). Cold glass can also create uncomfortable drafts as air next to the window is cooled and drops to the floor. It is then replaced by warmer air from the ceiling, which in turn is cooled. This sets up an air movement pattern that feels drafty and accelerates heat loss. Windows with an improved R-value glazing will result in higher glass temperatures. A relatively tight window will improve comfort by reducing cold air leakage.

In summer, comfort is based on reducing solar heat gain through windows and by reducing glass temperature. By selecting glazings that reduce solar heat gain by reflection instead of absorption, the interior window temperature is lowered and comfort improved. A window with poor energy performance characteristics will also be an uncomfortable window. Energy efficient window assemblies in terms of R-value and emissivity not only save on fuel costs, but provide an improved thermal comfort environment (Carmody et al., 1996).

Storm Windows

Haynes (1987) cited windows as the primary source of heat loss in a building because they are both a poor thermal barrier, with an average R-value of only 0.89 and often a source of air infiltration (p. 150). Adding storm windows greatly improves these poor characteristics. The

historic window plus storm window assembly will have an improved R-value averaging 1.79 which outperforms the average double paned window assembly that only has an R-value of 1.72 (National Park Service, 1978, p. 7).



Figure 6. Interior storm windows (National Park Service, 1978)

The decision to place storm windows on the inside or outside of the window depends on whether the window opens in or out, and on the visual impact of adding storm windows either on the exterior or interior appearance. Interior storm window installations can be as thermally effective as exterior storm windows; however, there is high potential for damage to the historic window and sill from condensation (Barista, 2001). Figure 6 above shows an example of interior storm windows installed on historic single pane windows. Condensation occurs when the glass temperature falls below the dew point of the room air temperature. With storm windows on the interior, the outer historic sash will be cold in the winter, and hence moisture may condense there. This condensation often collects on the flat surface of the sash or window sill causing paint to blister and the wood deterioration to begin.



Figure 7. Exterior storm windows (lowes, 2005)

The use of exterior storm windows should be investigated whenever feasible because they are thermally efficient, cost-effective, reversible, and allow for the retention of the original windows (National Park Service, 1981). Colors should be selected so that they match the existing trim color. Various configurations are available, even arched, in wood, vinyl, aluminum, or plastic. In addition to energy savings, external storm windows provide a layer of protection against air pollutants and vandals. Usually external storm windows partially obscure the prime historic window, but the storm window can always be removed during favorable weather seasons to expose the full view of the prime window. See Figure 7 for an example of exterior storm windows.

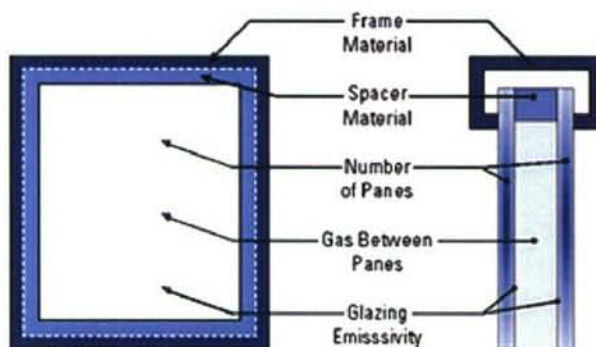


Figure 8. Factors affecting window thermal performance (wbdg, 2005)

Weatherization

Historic metal and some wooden windows are generally not energy efficient; this has often led to their wholesale replacement (National Park Service, 1984). Historic windows can, however, be made more energy efficient in several ways. Caulking and periodically repairing the caulking, around the masonry openings and adding weatherstripping are important first steps in reducing air infiltration around the windows (Ivy, 1992). Although weatherstripping is one of the least expensive components of a window, it can be responsible for as much as 50 percent of the window's energy performance (New York Landmarks Conservancy, 1992). The four common types of weatherstripping are spring-metal, vinyl strips, compressible foam tapes, and sealant beads (National Park Service, 1984). See Figure 9 for examples of weatherstripping.

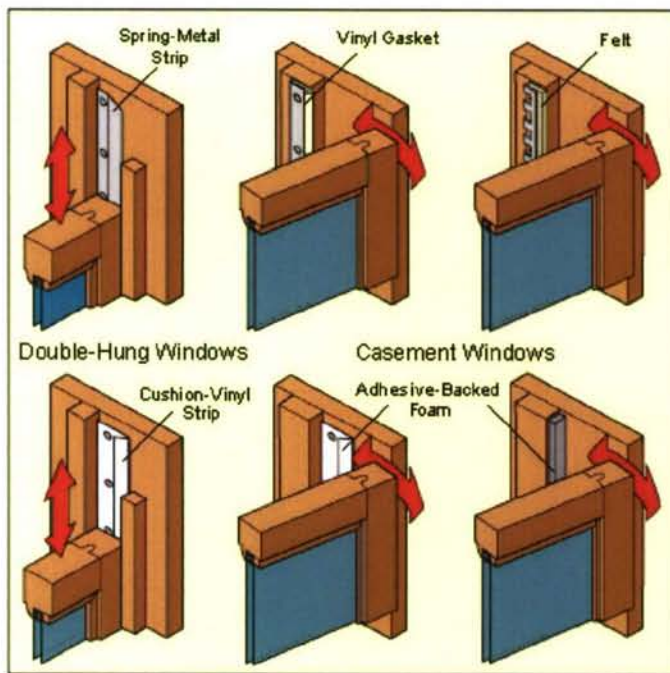


Figure 9. Examples of weatherstripping (aboutsavingheat, 2005)

Other treatments include applying fixed layers of glazing over the historic windows, or installing thermal glass in place of the existing glass (National Park Service, 1981). Each of the techniques for adding a layer of glazing will approximately double the original insulating value

of the windows; therefore, cost and aesthetic considerations usually determine the choice of method (National Park Service, 1984). The least expensive method is to install a clear material, such as rigid sheets of acrylic or glass, over the existing single pane window (Historic Preservation Education Foundation, 1997). The entire window opening can be covered in this manner or on a smaller unit basis with panels that affix to the sash with screws or gaskets. Condensation can be avoided by providing a small 1/8 inch opening at the top corner as a vapor bleed (New York Landmarks Conservancy, 1992). Single glazed window panels can be replaced with thermal glass or a secondary glazing can be applied. See Figure 10 below for example of double-glazing applied to existing window.

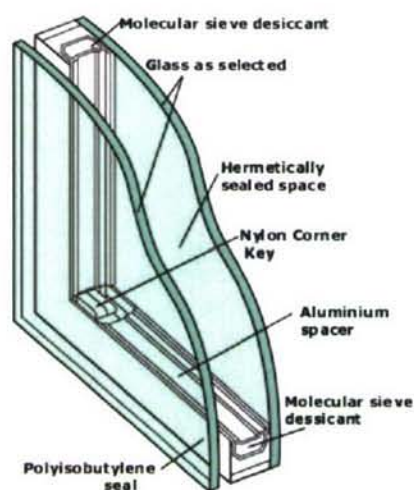


Figure 10. Hermetically sealed double-glazing (pilkington, 2005)

Sash and possibly muntin thickness will be the limiting factors for applying a secondary glazing, as an air space of 12 to 25 mm is required for best thermal performance in double glazing applications (Historic Preservation Education Foundation, 1997). If units are replaced with double glazed panels, then tinted glazing, low-E coatings, and gas-filled air spaces, with argon or krypton, can be analyzed.

Coatings, usually in the form of metal oxides, can be applied to glass during production, reflecting up to 90 percent of long-wave heat energy, while passing shorter wave, visible light (wbdg, 2005). In hot climates, they reflect the sun's long-wave heat energy while admitting visible light that is responsible for heat gains, thereby keeping the house cooler in the summer (Menzies & Wherret, 2005). In cold climates, they reflect long-wave radiant heat back into the house, again while admitting visible light. Low-E coatings improve the insulating value of a window roughly as much as adding an additional pane of glass does (Fisette, 1998). Combining low-E coatings with low-conductance gas fillings, such as argon or krypton, boosts energy efficiency by nearly 100 percent over clear glass (wbdg, 2005). In combination with caulking and weatherstripping, these treatments can produce energy ratings rivaling those achieved by new windows (National Park Service, 1978).

Replacement Windows

Unfortunately, a common weatherization measure, especially in larger buildings, has been the replacement of historic windows with modern double paned windows (National Park Service, 1978). As stated in the previous section adding exterior storm windows is a viable alternative to replacing the historic windows and it is the recommended approach in preservation retrofitting. However, if the historic windows are severely deteriorated and their repair would be impractical, or economically infeasible, then replacement windows may be warranted. The new windows, of either wood or metal, should closely match the historic windows in size, number of panes, muntin shape, frame, color and reflective qualities of the glass (Haynes, 1987).

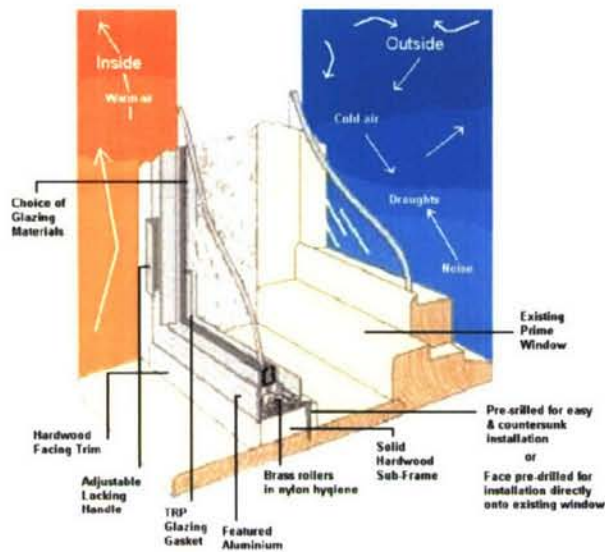


Figure 11. Interior double-glazing added to existing window (protechwindows, 2005)

Case Studies

Marquette Building Case Study

The 16-story Marquette Building, constructed in 1895, is one of Chicago's finest commercial buildings and is listed in the National Register of Historic Places. In the 1970's the occupancy rate fell to ten percent, and the decision was made in 1978 to renovate the building for prime office and retail space in Chicago's Loop (gsa, 2006). The modified Chicago-style windows, which fill the bays between the structural piers, are one of the most prominent features of the building's facade. Nearly 350 double-hung windows principally on the upper three floors and throughout the northern facade facing on an alley, the 182 Chicago-style windows were of greatest interest because of their style, prominence, and large size (gsa, 2006). See Figure 12 below for Chicago-style and double-hung windows. Although the windows vary in size, most measured about 12 feet wide by 8 feet high. Constructed out of quality mahogany, the windows were still in sound physical condition despite over ninety years of exposure to Chicago's winter weather and years of neglect due to deferred maintenance. While some of the sills needed repair, the windows primarily needed to be repainted and to have some interior trim replaced.



Figure 12. Marquette Building, Chicago circa 1895 (gsa, 2006)

In conjunction with a heating, ventilating, and air-conditioning (HVAC) analysis, the following three window alternatives were considered: a) repairing the existing windows and fixing them closed due to HVAC system, b) modifying the existing windows by installing insulated glazing for improved thermal performance, or c) replacing the existing windows with high-quality, aluminum units with insulating glass that matched the appearance of the original (gsa, 2006).

The estimated cost of repairing the windows was \$65,000, including the repair and reinstallation of fixed frames and glass in 28 windows where a material hoist and trash chutes were locating during the rehabilitation. The second alternative of modifying the existing sash examined the cost-effectiveness of installing insulated glazing in both the existing fixed panes and the double-hung sash throughout the building. This window work would achieve further savings by reducing energy consumption and permitting installation of a small HVAC system.

Construction costs, however, were estimated to be \$860,000. The estimated cost of aluminum replacement windows that matched the appearance, size and configuration of the existing windows was nearly \$1,600,000 (gsa, 2006). See Figure 13 showing entrance to the Marquette Building after completion of the renovation project.



Figure 13. Marquette Building storefront (gsa, 2006)

After an in-depth study of the repair, modifications, and replacement alternatives in which such factors as energy costs, construction costs, and finance charges were considered, the architect and owners determined that the most cost-effective solution was to repair the existing windows. Assuming the worst conditions for infiltration, insulating glass would have resulted at best in energy savings of 10 percent in heating costs and 15 percent reduction in cooling costs (gsa, 2006). Building management decided to save the money since there was a long, almost nonexistent pay back. Total rehabilitation cost was \$17,000,000 and the window repair cost, exclusive of the storefronts was \$65,000 (gsa, 2006).

Energy Savings and Economics of Retrofitting Single-Family Buildings Study

This study assessed the energy savings and cost-effectiveness of individual retrofit methods in single-family buildings, based on analysis of metered energy consumption and actual installation costs. The study sources data from several different studies conducted by universities, energy companies, and agencies in the U.S. and Canada during the late 1980's. Data on individual retrofit methods represent 32 different projects, ranging in size from three to 30,000 buildings (Cohen et al., 1991). Fourteen separate retrofit measures were analyzed, including attic, wall, ceiling, and foundation insulation, window replacements, heating and cooling system retrofits and replacements, and water heating retrofits (Cohen et al., 1991).

A sampling of the retrofit results is shown in Table 1. Cohen et al. (1991) show that both the installation of wall and ceiling insulation results are quite cost-effective by providing an average annual energy consumption savings between 12 and 21 percent and an average cost of conserved energy between \$1.60 and \$6.50 per GigaJoule (GJ). The data from this study shows that window replacements tend to be expensive with energy savings that are relatively small with an average annual energy consumption savings between two and five percent (Cohen et al.,

Measure	Data Source	Number Homes	% Avg Savings	Cost	Payback (yrs)	Cost of Conserved Energy /GJ
Water Heater Wrap	ORNL	20	12	\$22	0.5	\$0.40
Ceiling Insulation	Consol. Gas	71	13	\$630	4	\$1.90
Wall Insulation	Manitoba E&M	12	17	\$850	5	\$1.60
Flame Retention Burners	BNL	19	14	\$460	2	\$2.20
Furnace Replacement	Ball State Univ.	30	19	\$2,110	15	\$5.90
Replacement Windows	Manitoba E&M	89	5	\$940	49	\$16.00
	Ball State Univ.	41	2	\$3,350	450	\$180.00

Table 1. Average savings and economics of retrofit methods (Cohen et al., 1991)

1991). Window replacements were the least cost-effective retrofit and had the longest payback of initial investment of all the methods analyzed in this study.

Results of National Weatherization Evaluation

Approximately \$500 million is spent annually in the U.S. to weatherize low-income housing (Brown & Berry, 1995). Most of this funding originates from government agencies such as the DOE and the U.S. Department of Health and Human Services. In 1990, the DOE initiated a nationwide evaluation of the Weatherization Program to measure energy savings and cost-effectiveness.

Ten case studies of exemplary local agencies were conducted to identify keys to successful energy savings methods and program implementation. The main criterion for case study selection was higher than average natural gas or other heating fuel savings (Brown & Berry, 1995). Possibly the most interesting finding of ten case studies was that there were many different formulas and weatherization methods used for success.

Although there was a great diversity in the types of weatherization methods employed by various agencies, the measures that these agencies installed more than other agencies were: first-time attic and wall insulation, furnace retrofit and replacements, and water-heater measures. The case studies clearly showed that insulating attics and walls were both strongly associated with high energy savings (Brown & Berry, 1995). One consistently negative finding was that the investments in storm windows were associated with lower than average energy savings compared to other retrofit methods employed (Brown & Berry, 1995).

Vermont Residential Window Case Study

In 1994 a case study was performed in Vermont involving a large scale window upgrade project on various older homes. Sixty-four pre-treatment windows were tested for air leakage

rates serving as a baseline for later testing. Eighty-seven post-treatment windows were then tested after a wide variety of window treatment strategies had been applied (Historic Preservation Education Foundation, 1997). Table 2 below shows the different types of window treatments employed on the project.

Window Treatment Description	Quantity
Retained original sash	62
Replacement sash with vinyl jamb liners	11
Replacement window inserts	12
Whole window replacements	2
Replacement storm windows	17
Double- versus single-glazing replacements	19

Table 2. Windows tested by category (Historic Preservation Education Foundation, 1997)

Table 3 compares costs and savings for the different window treatment methods. The savings is related to the air leakage and cost savings compared to pre-treatment test results of the baseline windows. If the baseline windows had a tight fit, meaning low air leakage, then any upgrades typically have a very low rate of return. Possible lead abatement can have a negative impact on repairing windows versus replacement of windows. However, overall the first year savings range from \$14 to 20 regardless of the window treatment undertaken for a loose fitting window with high air leakage rates. Weatherstripping with a cost of \$75 can save \$15 in first year heating costs for a loose window, whereas installation of low-E inserts can cost up to \$500 with a first year savings on heating cost of only \$20, providing a much lower rate of return on cost to improve thermal performance of the window.

Category	Upgrade*	Cost	Cost with Lead Abatement**	First Year Savings Compared to Baseline Windows		
				Tight	Typical	Loose
Retain original sash	Vinyl jamb liners	\$175	\$300	\$0.00	\$0.80	\$14
	Weatherstripping	\$75	\$200	\$0.20	\$1.70	\$15
Replace Sash	Single glass sash	\$200	\$200	\$0.30	\$1.80	\$15
	Window inserts	\$250-500	\$250-500	\$1.90	\$3.40	\$16
	Low-E DG inserts	\$250-550	\$250-550	\$5.30	\$6.80	\$20
Storm Windows	New exterior	\$100	\$225	\$1.00	\$2.50	\$16
	New interior	\$115	\$240	\$1.30	\$2.80	\$16
	Interior low-E	\$155	\$280	\$4.70	\$6.20	\$19

* Cost for inserts include a range from medium cost vinyl insert windows to high quality wood inserts

** Full sash lead abatement costs of \$125 are included for all upgrades retaining existing sash

*** Savings are based on 7744 degree days, oil heat at \$0.90/gallon with 75% overall heating season efficiency

Table 3. First year heating cost savings (Historic Preservation Education Foundation, 1997)

Discussion

More than 30 percent of all construction in the United States now involves work on existing buildings (lowes, 2005). The federal government has commendable orders to both drastically reduce energy consumption of its facilities and at the same time preserve and maintain the character and significant features of its historic buildings. Federal construction dollars receive increasing scrutiny as all areas of the federal government are being pushed to downsize and optimize their workforce and real estate footprint. Consequently, with less new construction occurring, DOD bases and other government agencies are inclined to renovate and rehabilitate existing facilities to meet new or changing requirements.

Retention of historic structures on military facilities is not only mandated by policy, but is often critical in strengthening and maintaining overall military history and tradition. Many buildings and other structures on bases and posts throughout the world are historically significant in terms of military history because of the leaders that have served in those very facilities. Some structures are named after famous leaders or commemorate battles, agreements, treaties, and historic events. Military traditions and heritage are integral ingredients in the training and morale of future military leaders. Most military bases in the United States are 100 years old or more, with historic facilities abundantly scattered throughout each installation. Structures are rarely demolished on military bases, but instead retrofitted to meet new purposes (DOD implementation plan, 2002).

Studies have consistently shown that window retrofit or replacement methods are usually associated with lower than average energy savings when compared to other energy saving or weatherization measures that could be employed on a building (Cohen et al., 1991; Brown & Berry, 1995). Not only are the energy savings less significant than methods such as adding attic or wall insulation, but in the case of window replacements the high initial installation costs make the payback of this type of investment less attractive as well.

Historic preservation and energy conservation regarding window rehabilitation projects can be mutually achieved with proper repair and retrofit methods. The goal of most window rehabilitation projects is to upgrade the window's physical or thermal performance in addition to the esthetic appearance. Wholesale replacement of windows with high efficient modern windows for reasons of energy reduction actually contradicts many sustainable building principles by not attempting to conserve existing resources and materials. A historic wooden window with a high quality storm window added should thermally outperform a new double-

glazed metal window. This occurs because the wood has far better insulating value than the metal, and in addition many historic windows have high ratios of wood to glass, thus reducing the area of highest heat transfer.

High thermal inertia is the reason many older public and commercial buildings, without modern air conditioning, still feel cool on the inside throughout the summer. The heat from the midday sun does not penetrate the buildings until late afternoon and evening, when it is unoccupied. Although these characteristics may not typify all historic buildings, the point is that historic buildings often have thermal properties that need little improvement. One must understand the inherent energy saving qualities of a building, and assure, by reopening the windows for instance, that the building functions as it was intended. Sometimes solutions come from study of the past practices and methods rather than reliance on the latest technology.

Conclusion

Often repairing or rehabilitation of historic windows is less expensive than wholesale replacement of windows, with comparable energy reductions. But contrary to popular beliefs window replacements or even retrofits are not the most cost-effective energy reduction treatments that should be pursued as a first priority in a rehabilitation project. Rather measures such as attic, wall, and ceiling insulation, heating and cooling system retrofits, and water heating treatments should be executed long before considering window treatments to achieve more cost-effective energy savings.

Having shown that window retrofits are more cost-effective than window replacements, why do project and construction managers often choose to replace rather than repair? One reason for this replacement decision path is the design time and up front money involved in repairing or retrofitting windows. In order to properly repair historic windows considerably

more design and research is required to match profiles and colors, and to locate proper manufacturers or suppliers of historic window repair parts. Choosing to replace windows significantly reduces design time, historical research, and designer fees. Specifying a window replacement simply requires stipulating the proper size to fill the opening and the technical requirements for the new windows.

Often procurement time or deadlines for obligating funds can drive a decision towards replacement of windows versus repair. Military repair projects are funded with federal dollars that are only valid for one fiscal year, expiring on September 30th of each year. Unless significant information is readily available concerning the historic windows in question, or a previous design has been completed to repair the windows, there is usually not time to research and design window retrofits for the historic facilities and award a contract before the funds expire.

Replacement of windows versus repair is often perceived as being a clean and more professional method of design for a rehabilitation project. When the retrofit of windows is specified there are often varying degrees and methods of repair required for different areas of a building. If the windows are instead specified to be replaced, one common model can be chosen and the replacement method can be described in general terms to cover all of the windows to be replaced. The most significant factor in favor of replacing windows is the warranty period the owner obtains by replacing rather than repairing the historic windows.

Design time and costs, expiring funds, and warranties are three reasons that project and construction managers often choose to replace historic windows rather than repair them even though studies consistently show that retrofitting windows is more cost-effective for comparable energy savings. Further research should be conducted regarding the management decision-

making factors surrounding repair versus replacement of historic windows. This research should attempt to uncover the root causes that lead project and construction managers to consistently choose to compromise historic integrity by replacing windows at ultimately a higher overall cost.

References

- About Saving Heat Website*. (n.d.) Retrieved November 21, 2005, from <http://www.aboutsavingheat.com/>
- Advisory Council on Historic Preservation. (1994). *Defense department compliance with the National Historic Preservation Act: Section 202(a)(6) evaluation report*. Washington, DC: US Government Printing Office.
- Barista, D. (2001, July). Restored vision. *Building Design and Construction*, 42(7), 106-108.
- Brown, M. A., & Berry, L. G. (1995, August). Determinants of program effectiveness: results of the National Weatherization Evaluation. *Energy*, 20(8), 729-743.
- Carmody, J., Selkowitz, S., & Heschong, L. (1996). *Residential windows: a guide to new technologies and energy performance*. New York: W. W. Norton & Co. Inc.
- Cohen, S., Goldman, C., & Harris, J. (1991, April). Energy savings and economics of retrofitting single-family buildings. *Energy and Buildings*, 17(4), 297-311.
- Department of the Air Force. (2004). *Air Force Instruction 32-7065 cultural resources management program*. Washington, DC: US Government Printing Office.
- Department of the Army. (1998). *Cultural resources management*. Washington, DC: US Government Printing Office.
- Department of Defense. (2002). *Department of Defense implementation plan for FY2002*. Washington, DC: US Government Printing Office.
- Department of Defense. (1996). *Department of Defense Instruction 4715.3 environmental conservation program*. Washington, DC: US Government Printing Office.
- Department of the Navy. (2004). *Department of the Navy FY2004 annual energy management report*. Washington, DC: Secretary of the Navy.
- Department of the Navy. (2001). *Department of the Navy cultural resources program (SECNAVINST 4000.35A)*. Washington, DC: Secretary of the Navy.
- Federal Energy Management Program*. (n.d.) Retrieved October 23, 2005, from <http://www.eere.energy.gov/femp/>

- Fisette, P. (1998, March). Understanding energy-efficient windows. *Fine Homebuilding Magazine*, 114, 68-73.
- Haynes, W. (1987, June). Windows: techniques for restoration and replacement. *Architectural Record*, 175(7), 150-153.
- Henck, C. (1990, July). Building renovation with continued occupancy. *ASHRAE Journal*, 32(7), 18-22.
- Historic Preservation Education Foundation. (1997). *Window rehabilitation guide for historic buildings*. Washington, DC: US Government Printing Office.
- Hodges-Fulton, G. J. (2004, March). *Decision support system for scoping the repair of old and historic windows*. Heckman Bindery, Inc., Manchester, Indiana.
- Ivy, R. (1992, April). Preserving historic windows. *Architecture*, 81(4), 90-96.
- Lowes Home Improvement Center Website. (n.d.) Retrieved November 23, 2005, from <http://www.lowes.com/>
- Menzies, G. F., & Wherret, J. R. (2005, March). Multiglazed windows: potential for savings in energy, emissions and cost. *Building Services Engineering Residential Technology*, 26(3), 249-258.
- New York Landmarks Conservancy. (1992). *Repairing old and historic windows*. New York City, NY: John Wiley and Sons, Inc.
- National Park Service. (1978). *Conserving energy in historic buildings* (Historic Preservation Brief No. 3). Washington, DC: US Government Printing Office.
- National Park Service. (1981). *The repair of historic wooden windows* (Historic Preservation Brief No. 9). Washington, DC: US Government Printing Office.
- National Park Service. (1984). *The repair and thermal upgrading of historic steel windows* (Historic Preservation Brief No. 13). Washington, DC: US Government Printing Office.
- National Renewable Energy Laboratory. (n.d.) Retrieved October 25, 2005, from <http://www.nrel.gov/femp/>
- Padjen, E. (1995, November). Repairing historic windows. *Architecture*, 84(11), 151-157.
- Pilkington Website. (n.d.) Retrieved November 20, 2005, from <http://www.pilkington.com/applications/products/>
- ProTech Windows Website. (n.d.) Retrieved November 23, 2005, from

<http://www.protechwindows.com/secondaryglazingfacts.htm>

U.S. General Services Administration Historic Preservation Policy. (n.d.) Retrieved October 24, 2005, from <http://gsa.gov/>

U.S. General Services Administration Historic Preservation Technical Procedures – No. 08500-02. (n.d.) Retrieved February 7, 2006 from <http://w3.gsa.gov/web/>

Windows and Glazing. (n.d.) Retrieved January 18, 2006 from http://www.wbdg.org/design/historic_pres.php