CHAPTER 3

PLANNING AND SPECIFYING FOR REHABILITATION AND REPLACEMENT

The Assessment of Existing Window Systems, *Stephen J. Kelley, AIA, SE*

Life Cycle Cost Analysis for Restored and Replacement Windows, *Jean-Yves Tremblay and Craig Sims*

Aluminum Replacement Windows: Design Issues, Performance, and Quality Control, *David S. Patterson, AIA, Dennis K. Johnson, and Joseph M. Walaszek*

Replacing Steel Windows with Steel Windows: Crosley Estate/Seagate, Manatee County, Florida, *Linda D. Stevenson, AIA*

Designing a Replacement Window to Fit Your Needs, *Richard Graf*

Specifying Wood Window Repair and Replacement, *William G. Foulks*
THE ASSESSMENT OF EXISTING
WINDOW SYSTEMS

Stephen J. Kelley, AIA, SE
Senior Consultant
Wiss, Janney, Elstner Associates, Inc.
Chicago, Illinois

Introduction
In a typical facade rehabilitation project, windows represent a sizeable portion of the building's envelope and a significant portion of the project cost. Windows can require rehabilitation for conditions which include water leakage, excessive air infiltration, poor thermal performance, material deterioration, and structural failure. The factors that cause these conditions include aging, lack of maintenance, and poor design, fabrication, or installation.

Some previous window rehabilitation strategies performed during the energy crisis of the 1970s were ill conceived and did not adequately address problems. A challenge encountered when renovating a facade is determining proper procedures for rehabilitating the windows. This can only be determined once an adequate assessment is performed and the data properly interpreted.

This paper discusses the parameters encountered in window assessment, proposes an approach to window assessment, and introduces published sources that aid in window assessment. Though the information is set forth as a guide, it should be understood that some of the best tools of the investigator: knowledge, training, and experience, cannot be successfully imparted in a manuscript. In addition, the comprehensiveness of an assessment will vary with the facade being investigated, and it will be up to the practitioner to determine what steps beyond a simple visual inspection might be required for a specific project.

Parameters of Window Assessment
Numerous types and configurations of windows exist. They are composed of different types of materials. They are located in buildings of every type, buildings of all ages, and buildings located in every region of the country and will be subjected to the environment unique to that region. These parameters must be understood and considered in a window assessment, as discussed below.

Building Location
This is certainly the most obvious of the parameters to be considered but still deserves mention. Variances in temperature, humidity, average rainfall, and wind characteristics of each region need to be understood in any assessment. Air infiltration and frost condensation are characteristics that may only be of concern in cold climates, whereas various algae, slime, and mildews thrive in moist environments of warmer climates. Special concerns exist on sea coasts where salt laden air can accelerate deterioration of metals and finishes. Within the larger natural environment, micro-climates may be established by the presence of manufacturing facilities and the like. Locations with unusually high levels of pollutants or sound may define special conditions of the window assessment. Problems may emerge from differences between indoor and outdoor conditions and the systems needed to sustain these differences in locations where the environment is extreme or variable. In addition to the factors associated with the location of the building itself, factors are associated with window location.
within a particular building elevation, as exemplified by the increased wind pressure found at the upper regions and building corners of skyscrapers.

**Building Types**

Approaches to window assessment will vary according to the structure in which the windows are a part. A series of performance testing procedures may be prudent on a 35-story building with thousands of the same window while a two-story house may only require a simple visual survey. Residential and industrial facilities may have special natural ventilation requirements that do not come into play at an office building.

Hospitals and schools are concerned about sound control, and some hospitals have special air infiltration criteria due to patients with severe allergies. Access may be limited or strictly controlled in hospitals or residential highrises which will affect the assessment process.

**Building (and Window) Vintage**

The age of the window fabric is important to know, and not just in terms of how the material has aged. The context of the window in light of the history of the technologies that were a part of its fabrication and installation will shed light on fabrication techniques, possible repair scenarios, and may uncover past rehabilitations that were otherwise not noticeable.

**Window Types**

Windows are either fixed or operable, and are often grouped together in various combinations of fixed and operable units. Types of operable windows include those designed for ventilation (double-hung, casement, sliding, and hopper windows), those that are generally only appropriate for low-rise residential buildings where performance and/or safety is not a consideration (awnings, vertical sliders, greenhouse windows, jal-awning and jalousie windows), and those designed for exterior access (top-hinged and vertically pivoted windows). There are other non-standard types of operable windows that can be found in older buildings.

Windows can either operate in-plane, or out-of-plane. In-plane operation occurs when the window moves parallel to the plane of the wall surface where the window is installed. Typical window types exhibiting in-plane movement are double-hung and sliding windows. Out-of-plane operation occurs when the window moves away from the parallel position in the wall. Typical window types exhibiting out-of-plane movement are casement, pivoting, and projecting windows.

In-plane and out-of-plane windows require different construction techniques for proper performance. They employ different concepts to achieve watertightness. In-plane operable windows require hardware such as counterbalances, springs, or rollers to aid in operation. Operating handles are normally separate from locking devices. Weatherstripping may be spring or interlocking metal type or, in more contemporary systems, pile or comb type. Screens when present will normally be on the exterior. On the other hand, out-of-plane operable windows require such operational hardware as hinges, limiting arms, and cranks. Operating handles can also act as locking devices. Weatherstripping is of the compression type such as break metal or rubber gaskets. Screens on outward operating windows will have to be located on the inside of the window.

Different window types may offer distinct performance characteristics inherent to their type. For instance, windows operating out-of-plane will generally seal better than windows operating in-plane resulting in better air infiltration and water penetration resistance.

**Window Materials**

Knowledge regarding the behavior and durability of window frame and sash materials is important for evaluating windows. All window materials, if properly maintained, can last a long time. In addition, operating hardware, weatherstripping, and glazing techniques may be determined by the window frame material. Below is a brief discussion of some general qualities of different window materials.

**Wood Windows.** The earliest known windows were made of wood. Today, wood is still a common window material that is used extensively in residential construction. Wood windows offer the warm, natural appearance of wood.
An advantage of wood windows includes the fact that wood is a good insulator, and wood frames do not transmit heat or cold as much as metal windows. Contemporary wood windows clad in aluminum or vinyl take the advantage of the insulating qualities of wood, while giving the window a "low maintenance" covering.

Disadvantages of wood windows include high maintenance requirements, and seasonal volume changes that can affect smooth operation. Wood members have a tendency to swell when subjected to moisture.

**Steel Windows.** In the early nineteenth century, windows constructed of cold rolled steel profiles were used in industrial buildings because they offered superior fire resistance. Their thin sight lines and elegant appearance made them popular in construction of the 1920s and 1930s. Another type of steel window which was popular before and after World War II was that composed of sheet metal formed into frame and sash members, commonly referred to as hollow metal frames.

An advantage of steel windows is that their rolled steel construction with welded corners is quite strong and sturdy. Their strength means that the required frame and sash member sizes are thinner, relative to other materials. Thin, elegant sight lines are achieved in steel as in no other window frame material. Hollow frame windows reduce the weight of the frames. Another advantage is that steel window construction is the only one that is fire-rated.

One of several disadvantages of steel windows is that metal construction provides poor thermal comfort. Corrosion of steel frames and sash is a maintenance concern. Frame corrosion can eventually break glass, affect window operation, and damage surrounding masonry. Paint build-up applied to mitigate corrosion can keep windows from performing and operating properly. Corroded rolled steel frames are much easier to maintain than hollow metal frames because the sheet metal will easily corrode and may become breached before the corrosion becomes noticeable. Because dissimilar metals will tend to react with steel in the presence of water, non-steel fittings and fasteners can intensify corrosion problems.

**Aluminum Windows.** Lightweight, workable, and resistant to corrosion, aluminum became popular in contemporary building construction for such applications as curtain walls, windows and doors, architectural trim, and siding.

Unfinished aluminum naturally acquires a gray patina as a result of weathering and corrosion. This appearance may or may not be acceptable. Cleaning and maintenance procedures may be required to prolong the service life of aluminum by retarding corrosion. Aluminum oxide formed on unprotected aluminum provides protection to the underlying metal, but also provides a base for accumulation of airborne dirt particles.

Aluminum windows were introduced into the U.S. market in the late 1920s but did not become an economical alternative to wood and steel windows until after World War II. In the last 20 years, aluminum windows have captured the largest share of the window market of combined residential and commercial uses, and aluminum has become almost ubiquitous in curtain wall construction.

An advantage of aluminum windows is the low maintenance of the metal itself. Aluminum is resistant to corrosion because of the tough, tenacious, and transparent aluminum oxide film that forms on its surface.

The disadvantages of aluminum windows include their poor thermal characteristics because the metal conducts heat and cold. Modern aluminum windows incorporate thermal breaks that improve thermal qualities by reducing conduction heat transfer across the window frame. Thermal break construction, however, dictates a weaker frame construction, where the frame on each side of the thermal break has a tendency to act separately from the other side. The aluminum material has lower strength characteristics than other metals, so aluminum windows will have larger frame members, referred to as sight lines, than steel windows used in the same installation. Thermally improved frames will make aluminum window sight lines even larger. Unfinished (referred to as mill finished) aluminum surfaces may oxidize unevenly over a long period of time which will appear as an unsightly white residue or pitting. Aluminum is a highly cathodic metal, and will tend to react electrolyti-
ally with anodic metals in the presence of water, thus destroying the aluminum.

"Vinyl" (PVC) Windows. Windows made of PVC or vinyl have only recently come into use, and are generally used only in residential construction. Although these windows have been utilized in Northern Europe for more than two decades, they do not yet have a long track record in the United States.

Among the advantages of PVC windows are their low cost and ease of fabrication. PVC is a good insulator, and the windows offer superior thermal performance. Fabrication processes which heat weld mitered corners directly together provide the windows with superior strength and airtightness.

The disadvantages of PVC windows include the tendency of plastics to break down in ultra-violet light. Consequently, PVC windows will not normally be found in the southern parts of the U.S. Vinyl expands and contracts much more than wood, aluminum, or steel, and can warp as a result of environmental stresses. The long-term effects of temperature extremes and exposure to sunlight on vinyl windows are still unknown. Due to its inherent qualities, vinyl frames are thicker than frames of windows made of other materials.

Glass and Glazing. This could be the topic of another paper. Suffice it to say that there are glasses that originate from different fabricating processes that would chart the history of glass-making including blown, cast, annealed, ground and polished, and float. Specialty glasses include patterned glass, wire glass, stained and leaded glasses, tempered glass, insulated glass units, and laminated glass. Glass may be tinted or coated with reflective or thermal films. Glazing methods can be categorized by window frame material and range from putties and sealants to rubber, neoprene, and PVC gaskets. Glass may be held in place with points and glazing stops of wood, plastic, or metal. Blocking can be wood, rubber, neoprene, or other material.

An Approach to Window Assessment

Because windows create an opening in the building envelope and perform multiple roles, distress within a facade is often concentrated at or around windows. When assessing windows, the window should not be considered as a separate entity but as part of the wall system. Substandard performance of the wall system may result in problems that are attributed to the window, but that are actually caused by the adjacent wall. Therefore, consideration of surrounding wall conditions is important in the investigation.

The following assessment procedures range from basic to sophisticated. Basic techniques which should be implemented first often help determine the necessary sophisticated techniques to complete the assessment. It is highly likely that for some projects, sophisticated assessment techniques will not be helpful, and the judgement of the practitioner is required to develop an appropriate assessment strategy. The techniques listed below are in order from basic to sophisticated.

Document Review

The architectural, structural, and shop drawings, and the specifications, if available, should all be reviewed to understand the original intent of the window system. Drawings and specifications can shed light on the relationship of the window to the wall system, the presence and location of flashings, conditions hidden within the wall, and the type of connections utilized. It should be noted, however, that window systems are not always realized in strict accordance with the plans of the architect. The shop drawings, if available, are typically accurate to precise detail. Review of previous reports and repair procedures may also shed light on the window system make-up, and shortcomings in window system performance.

Occupant Survey

After the document review, a general survey of the building's windows should be performed. In large buildings, the survey may take the form of a questionnaire to which building occupants are to respond. Due to reliance on non-technical help and the variance in percentage of response, the data received will be qualitative rather than quantitative but will provide insights into patterns of distress with the windows. Insight can be gained on the types of problems, their locations, their frequency, and conditions which cause the problems.

III-6 Window Rehabilitation Guide for Historic Buildings
Visual Inspection
After the document review and survey is completed, the windows should be closely inspected on the exterior and interior. This may require the use of scaffolding, a personnel lift, a swingstage, or the like. On large projects, representative windows may be inspected rather than inspecting every window. The inspection should determine if the window construction matches the original design documents. Conditions can be determined of all the parts that make up the window including window glazing, frame material, material finishes, hardware, screens, glass and glazing, and sealant joints. The operability of windows can be checked. Locations of water leakage or damage can be viewed. The type and amount of maintenance or repairs, such as paint coats, should be documented, and their success noted. The remainder of the wall and roof areas should also be observed for signs of potential problems that are not related to the window system, but which may be perceived to be a window problem.

Inspection Openings
Partial disassembly of a representative window and adjacent walls or deglazing a window can reveal concealed conditions. Window trim, glazing stops, glass, and hardware can sometimes be disassembled in order to expose connections and flashings. Inspection openings can be intrusive but are typically performed in areas where the fabric has already been damaged by water leakage, and will need repair. Disassembly can also reveal how a window system can be taken apart and reassembled without damage and will aid in design of its rehabilitation. When making inspection openings it is prudent to hire a window contractor, glazer, or other professional with expertise in this type of work to assure that as little damage as possible is made to the fabric.

Energy Analysis
An analysis of the thermal or energy performance of existing windows can be performed to determine the energy effectiveness of window systems. The estimated heating and cooling loads are generally calculated based on American Society of Heating, Refrigeration and Air-Conditioning Engineers, Inc. (ASHRAE) standards and methods. Basic information regarding actual energy usage and fuel costs can be obtained from the building owner or manager and used to calibrate the energy analysis. The results of the energy analyses can then be used as a basis for economic evaluation of various window rehabilitation strategies to improve thermal performance. It is important that the entire building envelope be analyzed, not just the windows within the envelope. Window thermal performance can be greatly improved but the improvement may be negligible when taken in the context of the entire wall enclosure.

Performance Testing in the Field
If water and air leakage was observed during the window inspection or survey, window testing is a useful tool to locate the causes of leakage. Testing can be performed to determine the strength of the window, its sound resistance, and its ease of operation. Testing more than one window is recommended in order to obtain representative window behavior. Based upon the findings of the investigation, different options can then be considered to improve performance.

Air Infiltration Performance. Air infiltration tests involve air pressure corresponding to a specified wind velocity and applied against the surface of the window to force air from the exterior to the interior. Once the pressure is stabilized, the air infiltration is measured on the interior side. A testing procedure accepted in the window industry is ASTM E 783-91 “Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors.”

Water Penetration Performance. The intent of water penetration testing procedures are to simulate a severe wind-driven rain, and typically involve the application of water against the exterior surface of the window at a rate corresponding to a rainfall of eight inches per hour. A negative induced test pressure is created on the window interior, which is related to recorded wind speeds of the region where the building and windows are located. A testing procedure accepted in the window industry is ASTM E 1105-90 “Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls, and Doors by Uniform or Cyclic Static Air Pressure Difference.” Another test that is performed without pressure is AAMA 501.2-83 “Field Check of Metal Curtain Walls for Leakage.” This test is
performed by progressively wetting the lowest horizontal joint in a window, then the intersecting vertical joints, and progressing upward until all desired joints are tested. The joints are wetted using a calibrated spray nozzle, adjusted to produce a constant water pressure.

It is sometimes helpful to create water testing procedures in the field that are tailored to specific problems or concerns. An example would be flooding the subsill of a weeped window system to determine whether the subsill leaks water. Custom-designed tests can be quite useful because they permit the practitioner to focus on particular aspects of a window system many tests rather than on the whole window, thereby allowing more tests to be performed.

Structural Performance. Field testing is intrusive, may require removal of interior finishes, and can be expensive and time consuming. There are no standard testing procedures for structural performance testing in the field, however, the following laboratory test can be field adapted: ASTM E 330-90, “Standard Test Method for Structural Performance of Exterior Windows, Curtain Walls, and Doors by Uniform Static Air Pressure Difference.” This test involves the application of a positive or negative pressure to the interior and exterior of the window. The test pressure is related to recorded wind speeds of the region where the building and windows are located. The actual performance of the window is determined by measuring temporary and permanent deflections in the window frame during the test. If the window is overloaded during a structural test, the window may fail and be damaged.

Sound Resistance Performance. Windows are part of a building’s sound barrier. In general, if the window is airtight, the amount of noise transmitted through the window will decrease. Windows are rated by Sound Transmission Class (STC). The sound transmission of a window can only be marginally affected by repair procedures. Window replacement, however, can dramatically reduce the sound transmission of a window. The introduction of storm windows can also reduce sound transmission. The reduction of the sound transmission of a window is often the sole criteria for window replacement in schools and hospitals.

Ease of Operation. Operability of a window is an important consideration, especially if the user has physical limitations. Testing procedures have to do with the calibration and measurement of the force that is taken to open and close the window.

Laboratory Testing
Laboratory testing of materials and finishes are useful to determine physical properties so that compatible repair procedures can be selected. New and existing paint and sealant samples may need to be evaluated in the laboratory to determine their compatibility with repair treatments. Samples of existing paint and putty can be tested to determine the presence of lead. Laboratory performance testing is rarely conducted on existing windows because it is less intrusive (and less costly) to test windows in place. However, there may be cases when laboratory testing for strength, water penetration, or air infiltration is warranted. Thermal performance testing to measure insulating performance (U-value) and resistance to condensation (CRF) can also be implemented.

Published Sources for Window Assessment
There are numerous sources for technical guidance on window assessment, though a complete list is beyond the scope of this article. Several better known sources that are worthy of note are The Window Handbook, edited by Charles Fisher and published by the National Park Service in 1985; the series of Preservation Briefs and Tech Notes published by the National Park Service, and Technical Notes published by the Association for Preservation Technology International (APT).

Guidance in setting “design pressures” for wind loads and thermal criteria are typically established in local building codes, the more common ones being the Building Officials Code Administration (BOCA), the Uniform Building Code (UBC), and the Southern Building Code (SBC). The ANSI A58.1-1982 “Building Code Requirements for Minimum Design Loads in Buildings and Other Structures” and the Canadian National Building Code have also proven helpful in establishing these parameters. A comprehensive
review of the code literature augmented by any available local meteorological data is recommended to establish loading and thermal criteria.

Minimum standards for new windows have been established by industry associations such as the American Architectural Manufacturers Association (AAMA) for aluminum windows, the Steel Window Institute (SWI) for steel windows, and the National Wood Window and Door Association (NWWDA) for wood windows. The American Society for Testing and Materials (ASTM) has adapted many of the standard test procedures developed by these industry associations. The direct adoption of performance levels set by industry organizations for new windows are normally not directly translatable for existing windows, and expected performance may ultimately be set by the judgement of the practitioner.

Conclusion

This paper has presented the parameters encountered in window assessment, an approach to window assessment, and introduces published sources that aid in window assessment. Some of the best tools of the practitioner involved in window assessment, however, are knowledge, training and experience, a commodity that is not successfully imparted in a manuscript. It is left up to the reader to decide how comprehensive an assessment should be and when guidance from a specialist should be sought.

Many of the tools of assessment outlined above are also helpful in evaluating trial rehabilitation procedures. Trial rehabilitation is recommended prior to full scale rehabilitation. Trial window work affords the opportunity to compare the appearance of proposed window rehabilitation. Field testing on trial window work can be performed to obtain a measurement of improvements in performance. Most existing field conditions can be observed and verified. Trial repairs that are in place for more than a year will give a measure of the durability of the repair. The approved sample window can also serve as the on-site project standard by which all remaining windows will be measured.

Notes

1 Landmark structures are held to different standards than other existing structures without landmark status. Windows may be significant to the historic character of an older building, contributing to the highly visible features of the exterior and the interior. That is why on a landmark structure it may be preferable to retain, repair and restore rather than replace the existing building fabric including older wood or metal windows.

2 The window industry recognizes these performance variances, which is reflected in the voluntary performance standards established for different window types.

3 This property of wood is counted on by the wood industry to assure tight joints that retard water leakage.

4 Steel windows are not manufactured with thermal breaks like some aluminum windows.

5 There is a tendency to use the term "aluminum" when describing aluminum and its alloys. Aluminum alloys have varying strength and durability characteristics. Commercially used aluminum is almost always an alloy rather than pure aluminum. This paper will stay with convention and refer to the aluminum alloy family as aluminum.

6 Performance testing is also a useful tool for measuring the effectiveness of repairs.

7 At present, the test pressure is established by the industry and is not specifically related to local weather patterns.

8 In general, the induced test pressure is created by constructing a chamber on the interior of the window. The chamber should be large enough to include not only the window unit itself, but the window perimeter sealant joints as well, so that the entire window installation is tested for verification of field performance.

9 At present, the U-value and the Condensation Resistance Factor or CRF of a curtain wall system cannot be determined by field testing due to the complexity and size of equipment that is required to perform such testing.

10 The American Society for Testing and Materials (ASTM), established in 1898, is an organization of professionals from different disciplines who develop voluntary standards, guides, practices, and test procedures. ASTM Committee E6 focuses on standards for building construction which are widely used in the building profession. Standards for window performance are developed in ASTM Committee E6, “Building Construction.”
LIFE CYCLE COST ANALYSIS FOR RESTORED AND REPLACEMENT WINDOWS

Jean-Yves Tremblay
Heritage Conservation Architect
National Capital Commission
Ottawa, Ontario

Craig Sims
Architectural Preservation Consultant
Kingston, Ontario

Introduction

This study is based on window restoration and replacement projects undertaken by the National Capital Commission, (NCC) Ottawa, Ontario. It builds on an earlier study prepared in 1993 by the NCC entitled Standard and Costing for Window Rehabilitation.

The purpose of this study is twofold: to provide costing information, based on completed projects, which will aid in estimating capital costs for other similar projects; and to provide a life cycle cost analysis so that design choices, such as whether to restore and upgrade or replace windows, can be better understood in terms of initial capital costs plus maintenance and energy saving costs over a 20 year period.

This life cycle cost analysis approach to asset management is becoming the standard method used by numerous governmental agencies to financially compare various life cycle window options. All costs are presented in Canadian dollars per square foot.

Context

All of the projects presented have been undertaken in the past ten years and most are in classified or recognized buildings as listed by the Federal Heritage Building Review Office (FHBRO). In 1996 FHBRO published a Code of Practice based on international conservation charters, to serve as a guide to decision makers charged with the care of Crown-owned historic buildings. On page 42 in section 7.3 windows are discussed; this section reads in part:

- Historic window units should be retained and upgraded rather than replaced. The need for improved thermal performance is best met with interior or exterior storm windows rather than new sealed double or triple units [and] new weather stripping can be added to either the sash or the frame.

- Frequently, historic windows which have deteriorated only slightly over a hundred years are being replaced with modern units which have life expectancies of twenty or thirty years. Heritage character is best protected by the repair and upgrading of original or early window units.

- When replacement is required, new units should match the material, profile, and detail of the original. This approach maintains heritage character and maintains compatibility with surviving examples of original sash.

The case studies presented in this paper were all projects undertaken and developed within these guidelines or earlier versions of them.

For a detailed breakdown of capital costs for each project see the individual Case Studies.
Case Studies #1 through #9 have been used for the life cycle cost analysis because they represent projects that are similar in size; all are residential scale buildings with residential scale windows.

Table 1 - Summary of Various Window Restoration Projects in 1996

This table is based on 9 NCC case studies and describes various window interventions and the capital cost of those interventions on a square foot basis. Similar interventions are grouped together so that both the cost for the specific project and the average cost for that type of intervention can be seen. There are many possible reasons for the variations in cost for similar activities on different projects; for example, the project size, the state of the local economy at the time of tender, the time of year, in addition to peculiar project conditions.

Prices have been adjusted based on the 1996 Yardsticks for Costing that lists the historical price changes for Ottawa; all prices include seven percent GST (Goods and Services Tax).

Table 2 - Life Cycle Maintenance & Saving Costs per Square Foot Based on a 20 Year Time Period with a 2.1% Inflation Factor

This table identifies various maintenance and energy costs on a square foot basis over a 20 year time period. Specifically, it addresses:

- glazing replacement costs
- painting costs based on a 5 year time period
- annual energy saving costs
- annual storm and screen installation costs

Glazing Replacement Costs
As a worse case scenario, sash with single glazing can require as much as one percent glazing replacement annually; this would translate into almost complete replacement over a 100 year period. Replacement of single glazing mounted in putty is estimated to cost $65.00 per pane; assuming four panes per window, with a finished opening size of 3' x 6', the annual replacement cost based on one percent annual replacement would be about $0.15 per square foot. Because storm windows are subject to more handling they may require as much as two percent glazing replacement annually estimated to cost $0.30 per square foot.

Insulated glass units are usually guaranteed for an initial five year period. Glazing replacement is usually required because of seal failure caused by exposure of the edge seal to moisture. After the initial five year period, it is anticipated that the units would require replacement at an annual rate of two percent during the remaining 15 year period. The annual replacement cost is estimated at $0.30 per square foot.

Regular Maintenance Costs
The regular maintenance painting program is based on a five year time period. The estimated costs include painting of all interior and exterior window components, and repairing of all damaged putty and recaulking where required. It is assumed that the cost of a major restoration project could be avoided if maintenance was undertaken regularly.

- screen painting is estimated at $1.25 per square foot
- storm painting is estimated at $1.67 per square foot
- window painting with single glazing is estimated at $2.72 per square foot to allow for touch-ups to glazing putty
- window painting with double glazing is estimated at $2.30 per square foot

Calculated Energy Saving Costs
A calculated energy savings based on the 541 Sussex Drive project (NCC Case Study #4) indicated that new sashes mounted with clear single glazing and weather stripping would provide an estimated annual energy savings of 30,671 kWh or $920.00 for the entire project. The net saving would be $0.38 annual energy savings per square foot. In comparison, if the same project had been done with a low e insulated glass unit filled with argon gas, it would provide an estimated annual energy saving of 98,600 kWh or $2,958.00 for the entire project. The net saving per window would be $1.25 annual energy savings per square foot. These
savings are shown in Table 2 and are deducted from the other expenses.

Air infiltration testing indicated that the method followed for the restoration or upgrading of the single hung windows met the A1 rating whereas the casement windows met the A2 rating as described below. The following are the ratings for air tightness as listed in CAN/CSA-A440-M90:

<table>
<thead>
<tr>
<th>Window Rating</th>
<th>Max Air Leakage Rate (m3/hr/m-l)</th>
<th>Max Air Leakage Rate (cfm/in. ft. crack)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storm</td>
<td>1.498 (max.)</td>
<td>0.087 (min)</td>
</tr>
<tr>
<td>A1</td>
<td>2.79</td>
<td>0.501</td>
</tr>
<tr>
<td>A2</td>
<td>1.65</td>
<td>0.266</td>
</tr>
<tr>
<td>A3</td>
<td>0.55</td>
<td>0.069</td>
</tr>
<tr>
<td>Fixed</td>
<td>0.25</td>
<td>0.045</td>
</tr>
</tbody>
</table>

The Ontario Building Code describes the A1 and A2 ratings as follows: Windows with an A1 rating are intended for use primarily in low-rise residential (i.e., buildings of 3 stories or less and having an area not exceeding 600 square meters, or 6460 square feet), industrial and light commercial buildings. Windows with an A2 rating are intended primarily for use in medium to high rise residential, institutional and commercial buildings.

**Annual Storm and Screen Installation Costs**

Because screen and storm windows are frequent requirements in residential buildings, the costs associated with their seasonal installation, removal and storage must be taken into account. This cost is estimated to be $0.31 per square foot each, for a total of $0.62 per square foot.

**Table 3 - Window Restoration Units - Life Cycle Maintenance & Saving Costs per Square Foot Based on a 20 Year Time Period - 2.1% Inflation / 6% Discount Rate**

This table takes the life cycle costs and savings from Table 2 for the various window components, such as screens, storms and glazing type, and indicates the effect of inflation on those estimated costs in 1996 $ and establishes the present value of those future amounts. It works as follows:

By the year 2015, for example, the screen unit will have cost, in 1996 dollars, a total of $11.20 per square foot to maintain (see column “Estimated Cost 1996 $ Sum D+J”). Inflation will have increased the cost to $14.00 (see column “Estimated Cost in Budget Year @ 2.1%”). If the building owner wanted to invest now in 1996 dollars to have the $14.00 in the year 2015, the owner would have to invest $6.47 (see column “Present Value 1996 $ @ 6% Discount Rate”).

**Table 4 - 20 Year Cash Flow Projections for Window Restoration (Initial Cost of Restoration + 20 Year Life Cycle Maintenance and Saving Costs)**

This table illustrates the total present value per square foot in 1996 dollars for various window restoration options (see column “Various Window Restoration Options”). This value is obtained by taking the capital cost of the option from Table 1 (see column “A”) and adding to it the life cycle maintenance and savings costs (see column “B) from the “Present Value 1996 $” columns shown in Table 3.

**Table 5 - 20 Year Cash Flow Projections for Window Restoration Showing Four Different Schemes**

This table summarizes the total present value per square foot in 1996 $ for single hung and casement options. Four different schemes, or levels of intervention, are shown: these illustrate that a full restoration approach (Scheme #1) costs 20 percent less than the full replacement approach (Scheme #3).

The full replacement option, Scheme #3, was done with an insulated glass unit and did not require a storm window. The full restoration option, Scheme #1, including restored screens and storms, still remains the most economical approach.

**Summary**

The figures shown in Table 5 illustrate that when the cost of restoration, energy and maintenance are considered over 20 years, the preservation and upgrading of original windows compares very favourably to the cost of replacement units in the context of FHBRO classified buildings. The comparisons are considered to be valid for residential scale buildings containing 30 to 40 windows.
Although this study only looks at windows over a 20 year period, properly maintained original windows may last indefinitely. All too often the costs of good quality restoration work is weighed against the cost of new replacement window units that may only have a service life of only 20 to 30 years.

Ideally, it should not be necessary to argue for the retention of historic windows on only economic grounds. The fact that the windows are architecturally significant and original to the building should be sufficient to merit their preservation.
Table 1.
Summary of Various Window Restoration Projects
Based on 9 NCC Case Studies

<table>
<thead>
<tr>
<th>Type of interventions</th>
<th>Cost per sq. ft. based on year of construction</th>
<th>Year of Construction</th>
<th>Inflation index cost adjustment</th>
<th>Plus 7% GST</th>
<th>Less 5% work stoppage</th>
<th>Avg. cost per sq. ft. in Jan. 96</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Removal of steel storm</td>
<td>$3.74</td>
<td>1993</td>
<td>$0.18</td>
<td>$3.92</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2 Aluminum screen replacement</td>
<td>$4.43</td>
<td>1991</td>
<td>-$0.08</td>
<td>$4.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>3 Screen restoration</td>
<td>$7.63</td>
<td>1996</td>
<td></td>
<td>$7.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4 Storm restoration / 10% putty</td>
<td>$8.80</td>
<td>1991</td>
<td>-$0.16</td>
<td>$8.63</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5 Aluminum insert sash restoration</td>
<td>$12.77</td>
<td>1993</td>
<td>$0.62</td>
<td>$13.39</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6 Exterior frame and sash restoration / casement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$14.29</td>
</tr>
<tr>
<td>- Case study #2 / 10% putty</td>
<td>$13.31</td>
<td>1991</td>
<td>-$0.24</td>
<td>$13.07</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #7 / Interior sill / dg</td>
<td>$13.39</td>
<td>1995</td>
<td>$0.46</td>
<td>$0.96</td>
<td>-$0.66</td>
<td>$14.31</td>
</tr>
<tr>
<td>- Case study #8 / 12% putty</td>
<td>$15.70</td>
<td>1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7 Exterior frame restoration / case study #9 / based on 1 unit only</td>
<td>$14.84</td>
<td>1996</td>
<td></td>
<td>$1.03</td>
<td>-$0.74</td>
<td>$15.01</td>
</tr>
<tr>
<td>8 Wood screen replacement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$18.58</td>
</tr>
<tr>
<td>- Case study #5</td>
<td>$20.58</td>
<td>1993</td>
<td>$1.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #7</td>
<td>$17.25</td>
<td>1991</td>
<td>-$0.32</td>
<td>$1.18</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #7</td>
<td>$16.74</td>
<td>1995</td>
<td>$0.58</td>
<td>$1.21</td>
<td>-$0.86</td>
<td>$18.30</td>
</tr>
<tr>
<td>- Case study #8</td>
<td>$15.28</td>
<td>1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #9</td>
<td>$19.00</td>
<td>1996</td>
<td>$1.39</td>
<td>-$0.99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>9 Frame and sash restoration / casement / 12%</td>
<td>$28.80</td>
<td>1996</td>
<td></td>
<td>$28.80</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10 Storm restoration</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$31.17</td>
</tr>
<tr>
<td>- Case study #9 / 30% putty</td>
<td>$26.82</td>
<td>1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #9 / 100% putty</td>
<td>$34.83</td>
<td>1996</td>
<td>$2.43</td>
<td>-$1.74</td>
<td></td>
<td></td>
</tr>
<tr>
<td>11 Exterior frame and sash restoration / single</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$33.52</td>
</tr>
<tr>
<td>- Case study #2 / 10% putty</td>
<td>$26.96</td>
<td>1991</td>
<td></td>
<td>-0.49</td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #6 / dg</td>
<td>$39.82</td>
<td>1996</td>
<td>$2.75</td>
<td>-$1.99</td>
<td></td>
<td></td>
</tr>
<tr>
<td>12 Wood storm replacement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$34.75</td>
</tr>
<tr>
<td>- Case study #3</td>
<td>$33.22</td>
<td>1993</td>
<td>$1.62</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #7</td>
<td>$31.72</td>
<td>1995</td>
<td>$1.10</td>
<td>$2.29</td>
<td>-$1.64</td>
<td></td>
</tr>
<tr>
<td>- Case study #8</td>
<td>$28.72</td>
<td>1996</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #9</td>
<td>$41.04</td>
<td>1996</td>
<td>$2.87</td>
<td>-$2.05</td>
<td></td>
<td></td>
</tr>
<tr>
<td>13 Shutter replacement</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$43.11</td>
</tr>
<tr>
<td>14 Frame and sash restoration / single hung</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$55.82</td>
</tr>
<tr>
<td>- Case study #4 / 15% putty</td>
<td>$45.05</td>
<td>1993</td>
<td>$2.20</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #5 / 100% putty</td>
<td>$48.97</td>
<td>1993</td>
<td>$2.90</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #7 / 100% putty</td>
<td>$54.73</td>
<td>1995</td>
<td>$1.91</td>
<td>$3.96</td>
<td>-$2.83</td>
<td></td>
</tr>
<tr>
<td>- Case study #9 / 100% putty</td>
<td>$65.64</td>
<td>1996</td>
<td></td>
<td>$4.59</td>
<td>-$3.28</td>
<td></td>
</tr>
<tr>
<td>15 Door, sidelights and frame restoration</td>
<td>$55.98</td>
<td>1996</td>
<td>$3.91</td>
<td>-$2.79</td>
<td>$57.17</td>
<td></td>
</tr>
<tr>
<td>16 Frame and sash restoration / casement / 100%</td>
<td>$56.05</td>
<td>1996</td>
<td>$3.92</td>
<td>-$2.80</td>
<td>$57.17</td>
<td></td>
</tr>
<tr>
<td>17 Frame restoration and sash replacement / single hung</td>
<td>$56.40</td>
<td>1993</td>
<td>$2.76</td>
<td>$59.16</td>
<td></td>
<td></td>
</tr>
<tr>
<td>18 Frame restoration and sash replacement / single hung / single hung</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$60.49</td>
</tr>
<tr>
<td>- Case study #4</td>
<td>$61.04</td>
<td>1993</td>
<td>$2.98</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #7</td>
<td>$52.97</td>
<td>1995</td>
<td>$3.88</td>
<td>$3.90</td>
<td>-$2.79</td>
<td></td>
</tr>
<tr>
<td>19 Staining and extended frame in lieu of storm</td>
<td>$61.94</td>
<td>1991</td>
<td>-$1.13</td>
<td></td>
<td>$60.80</td>
<td></td>
</tr>
<tr>
<td>20 Frame and sash replacement / casement</td>
<td>$78.41</td>
<td>1986</td>
<td>$27.49</td>
<td></td>
<td>$103.90</td>
<td></td>
</tr>
<tr>
<td>21 Frame and sash replacement / single hung</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>$126.76</td>
</tr>
<tr>
<td>- Case study #3</td>
<td>$133.74</td>
<td>1993</td>
<td>$6.55</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #4</td>
<td>$108.00</td>
<td>1993</td>
<td>$5.28</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>- Case study #5</td>
<td>$120.66</td>
<td>1991</td>
<td>-$2.21</td>
<td>$8.29</td>
<td></td>
<td></td>
</tr>
<tr>
<td>22 Frame restoration and doors, screens, transoms replacement / dg</td>
<td>$149.64</td>
<td>1996</td>
<td>$10.47</td>
<td>-$7.48</td>
<td>$152.63</td>
<td></td>
</tr>
</tbody>
</table>
Table 2.
Window Restoration Work
Life Cycle Maintenance & Saving Costs per sq. ft. Based on a 20 Year Time Period
2.1% Inflation

<table>
<thead>
<tr>
<th>YEAR</th>
<th>GLAZING REPLACEMENT COST PER SQUARE FOOT</th>
<th>REGULAR MAINTENANCE COST PER SQUARE FOOT BASED ON A FIVE YEAR TIME PERIOD</th>
<th>ANNUAL ENERGY SAVING COST PER SQUARE FOOT</th>
<th>ANNUAL INSTALLATION COST PER SQUARE FOOT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A</td>
<td>B</td>
<td>C</td>
<td>D</td>
</tr>
<tr>
<td>1980</td>
<td>$0.15</td>
<td>$0.15</td>
<td>$0.30</td>
<td>$0.30</td>
</tr>
<tr>
<td>1981</td>
<td>$0.16</td>
<td>$0.16</td>
<td>$0.32</td>
<td>$0.32</td>
</tr>
<tr>
<td>1982</td>
<td>$0.17</td>
<td>$0.17</td>
<td>$0.34</td>
<td>$0.34</td>
</tr>
<tr>
<td>1983</td>
<td>$0.18</td>
<td>$0.18</td>
<td>$0.36</td>
<td>$0.36</td>
</tr>
<tr>
<td>1984</td>
<td>$0.19</td>
<td>$0.19</td>
<td>$0.38</td>
<td>$0.38</td>
</tr>
<tr>
<td>1985</td>
<td>$0.20</td>
<td>$0.20</td>
<td>$0.40</td>
<td>$0.40</td>
</tr>
<tr>
<td>1986</td>
<td>$0.21</td>
<td>$0.21</td>
<td>$0.42</td>
<td>$0.42</td>
</tr>
<tr>
<td>1987</td>
<td>$0.22</td>
<td>$0.22</td>
<td>$0.44</td>
<td>$0.44</td>
</tr>
<tr>
<td>1988</td>
<td>$0.23</td>
<td>$0.23</td>
<td>$0.46</td>
<td>$0.46</td>
</tr>
<tr>
<td>1989</td>
<td>$0.24</td>
<td>$0.24</td>
<td>$0.48</td>
<td>$0.48</td>
</tr>
<tr>
<td>1990</td>
<td>$0.25</td>
<td>$0.25</td>
<td>$0.50</td>
<td>$0.50</td>
</tr>
<tr>
<td>1991</td>
<td>$0.26</td>
<td>$0.26</td>
<td>$0.52</td>
<td>$0.52</td>
</tr>
<tr>
<td>1992</td>
<td>$0.27</td>
<td>$0.27</td>
<td>$0.54</td>
<td>$0.54</td>
</tr>
</tbody>
</table>
Table 3.
Window Restoration Units *
Life Cycle Maintenance & Saving Costs per sq. ft. Based on a 20 Year Time Period
2.1% Inflation / 6% Percent Discount Rate

<table>
<thead>
<tr>
<th>YEAR</th>
<th>ELAPSED YEARS</th>
<th>SCREEN UNIT</th>
<th>STORM UNIT</th>
<th>CLEAR SINGLE GLAZING WINDOW UNIT</th>
<th>LOW E DOUBLE GLAZING WINDOW UNIT</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>ESTIMATED COST 1996</td>
<td>ESTIMATED COST IN BUDGET @ 2.1%</td>
<td>PRESENT VALUE 1996 @ 6% DISCOUNT RATE</td>
<td>ESTIMATED COST 1996</td>
</tr>
<tr>
<td>1996</td>
<td>0</td>
<td>$0.31</td>
<td>$0.31</td>
<td>$0.61</td>
<td>-$0.23</td>
</tr>
<tr>
<td>1997</td>
<td>1</td>
<td>$0.31</td>
<td>$0.32</td>
<td>$0.61</td>
<td>-$0.23</td>
</tr>
<tr>
<td>1998</td>
<td>2</td>
<td>$0.31</td>
<td>$0.32</td>
<td>$0.61</td>
<td>-$0.23</td>
</tr>
<tr>
<td>1999</td>
<td>3</td>
<td>$0.31</td>
<td>$0.33</td>
<td>$0.61</td>
<td>-$0.23</td>
</tr>
<tr>
<td>2000</td>
<td>4</td>
<td>$1.56</td>
<td>$1.70</td>
<td>$1.66</td>
<td>-$0.23</td>
</tr>
<tr>
<td>2001</td>
<td>5</td>
<td>$0.31</td>
<td>$0.34</td>
<td>$0.61</td>
<td>-$0.23</td>
</tr>
<tr>
<td>2002</td>
<td>6</td>
<td>$0.31</td>
<td>$0.35</td>
<td>$0.61</td>
<td>-$0.23</td>
</tr>
<tr>
<td>2003</td>
<td>7</td>
<td>$0.31</td>
<td>$0.36</td>
<td>$0.61</td>
<td>-$0.23</td>
</tr>
<tr>
<td>2004</td>
<td>8</td>
<td>$0.31</td>
<td>$0.37</td>
<td>$0.61</td>
<td>-$0.23</td>
</tr>
<tr>
<td>2005</td>
<td>9</td>
<td>$1.56</td>
<td>$1.88</td>
<td>$0.92</td>
<td>$2.28</td>
</tr>
<tr>
<td>2006</td>
<td>10</td>
<td>$0.31</td>
<td>$0.38</td>
<td>$0.17</td>
<td>$0.61</td>
</tr>
<tr>
<td>2007</td>
<td>11</td>
<td>$0.31</td>
<td>$0.39</td>
<td>$0.17</td>
<td>$0.61</td>
</tr>
<tr>
<td>2008</td>
<td>12</td>
<td>$0.31</td>
<td>$0.40</td>
<td>$0.18</td>
<td>$0.61</td>
</tr>
<tr>
<td>2009</td>
<td>13</td>
<td>$0.31</td>
<td>$0.41</td>
<td>$0.19</td>
<td>$0.61</td>
</tr>
<tr>
<td>2010</td>
<td>14</td>
<td>$1.56</td>
<td>$2.09</td>
<td>$0.69</td>
<td>$2.38</td>
</tr>
<tr>
<td>2011</td>
<td>15</td>
<td>$0.31</td>
<td>$0.42</td>
<td>$0.17</td>
<td>$0.61</td>
</tr>
<tr>
<td>2012</td>
<td>16</td>
<td>$0.31</td>
<td>$0.43</td>
<td>$0.18</td>
<td>$0.61</td>
</tr>
<tr>
<td>2013</td>
<td>17</td>
<td>$0.31</td>
<td>$0.44</td>
<td>$0.18</td>
<td>$0.61</td>
</tr>
<tr>
<td>2014</td>
<td>18</td>
<td>$0.31</td>
<td>$0.45</td>
<td>$0.19</td>
<td>$0.61</td>
</tr>
<tr>
<td>2015</td>
<td>19</td>
<td>$1.56</td>
<td>$2.32</td>
<td>$0.50</td>
<td>$2.38</td>
</tr>
</tbody>
</table>

EXAMINE SCREEN UNIT COMPARES WORK ACTIVITIES IDENTIFIED AT COLUMNS D & F (SCREEN PAINTING & SCREEN INSTALLATION) OF TABLE 2
Table 4.
20 Year Cash Flow Projections for Window Restoration
(Initial Cost of Restoration 20 Year Life Cycle Maintenance and Savings Costs)

<table>
<thead>
<tr>
<th>NO.</th>
<th>VARIOUS WINDOW RESTORATION OPTIONS</th>
<th>AVERAGE INITIAL COST PER SQ. FT. 1996$</th>
<th>B +: (20) YEAR LIFE CYCLE MAINTENANCE &amp; SAVING COST PER SQ. FT. 1996$ 6% DISCOUNT RATE</th>
<th>A +: (B)  TOTAL PRESENT VALUE PER SQ. FT. 1996$</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>SCREEN RESTORATION</td>
<td>$7.63</td>
<td>$6.47</td>
<td>$14.10</td>
</tr>
<tr>
<td>4</td>
<td>STORM RESTORATION / 10% PUTTY</td>
<td>$8.63</td>
<td>$11.02</td>
<td>$19.65</td>
</tr>
<tr>
<td>6</td>
<td>EXTERIOR FRAME AND SASH RESTORATION / CASEMENT</td>
<td>$14.29</td>
<td>$3.07</td>
<td>$17.36</td>
</tr>
<tr>
<td>8</td>
<td>WOOD SCREEN REPLACEMENT</td>
<td>$18.58</td>
<td>$6.47</td>
<td>$25.05</td>
</tr>
<tr>
<td>9</td>
<td>FRAME AND SASH RESTORATION / CASEMENT / 12% PUTTY</td>
<td>$28.80</td>
<td>$3.07</td>
<td>$31.87</td>
</tr>
<tr>
<td>10</td>
<td>STORM RESTORATION / 100% PUTTY</td>
<td>$31.17</td>
<td>$11.02</td>
<td>$42.19</td>
</tr>
<tr>
<td>11</td>
<td>EXTERIOR FRAME AND SASH RESTORATION / SINGLE HUNG</td>
<td>$33.52</td>
<td>$3.07</td>
<td>$36.59</td>
</tr>
<tr>
<td>12</td>
<td>WOOD STORM REPLACEMENT</td>
<td>$34.72</td>
<td>$11.02</td>
<td>$45.74</td>
</tr>
<tr>
<td>14</td>
<td>FRAME AND SASH RESTORATION / SINGLE HUNG / 100% PUTTY</td>
<td>$55.82</td>
<td>$3.07</td>
<td>$58.89</td>
</tr>
<tr>
<td>16</td>
<td>FRAME AND SASH RESORATION / CASEMENT / 100% PUTTY</td>
<td>$57.17</td>
<td>$3.07</td>
<td>$60.24</td>
</tr>
<tr>
<td>17</td>
<td>FRAME RESTORATION AND SASH REPLACEMENT / CASEMENT</td>
<td>$59.16</td>
<td>$3.07</td>
<td>$62.23</td>
</tr>
<tr>
<td>18</td>
<td>FRAME RESTORATION AND SASH REPLACEMENT / SINGLE HUNG</td>
<td>$60.49</td>
<td>$3.07</td>
<td>$63.56</td>
</tr>
<tr>
<td>19</td>
<td>AWWNING AND EXTENDED FRAME IN LIEU OF STORM</td>
<td>$60.80</td>
<td>$-7.93</td>
<td>$52.87</td>
</tr>
<tr>
<td>20</td>
<td>FRAME AND SASH REPLACEMENT / CASEMENT</td>
<td>$103.90</td>
<td>$-7.93</td>
<td>$95.97</td>
</tr>
<tr>
<td>21</td>
<td>FRAME AND SASH REPLACEMENT / SINGLE HUNG</td>
<td>$126.76</td>
<td>$-7.93</td>
<td>$118.83</td>
</tr>
</tbody>
</table>
Table 5.
20 Year Cash Flow Projections for Window Restoration
(Initial Cost of Restoration + 20 Year Life Cycle Maintenance and Savings Costs)

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Cash Flows</th>
<th>Single Hung</th>
<th>CaseMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>#3 Screen Restoration</td>
<td>$14.10</td>
<td>$14.10</td>
<td></td>
</tr>
<tr>
<td>#10 Storm Restoration</td>
<td>$42.19</td>
<td>$42.19</td>
<td></td>
</tr>
<tr>
<td>#14 &amp; #16 Frame and Sash Restoration</td>
<td>$58.89</td>
<td>$60.24</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$115.18</strong></td>
<td><strong>$116.53</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Cash Flows</th>
<th>Single Hung</th>
<th>CaseMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>#8 Screen Replacement</td>
<td>$25.05</td>
<td>$25.05</td>
<td></td>
</tr>
<tr>
<td>#12 Storm Replacement</td>
<td>$45.74</td>
<td>$45.74</td>
<td></td>
</tr>
<tr>
<td>#18 &amp; #17 Frame Restoration and Sash Replacement</td>
<td>$63.56</td>
<td>$62.23</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$134.35</strong></td>
<td><strong>$133.02</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Cash Flows</th>
<th>Single Hung</th>
<th>CaseMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>#8 Screen Replacement</td>
<td>$25.05</td>
<td>$25.05</td>
<td></td>
</tr>
<tr>
<td>#21 &amp; #20 Frame and Sash Replacement</td>
<td>$118.83</td>
<td>$95.97</td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$143.88</strong></td>
<td><strong>$121.02</strong></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Cash Flows</th>
<th>Single Hung</th>
<th>CaseMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>#2 Aluminum Screen Replacement</td>
<td>* $4.33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#19 Awning and Extended Frame in Lieu of Storm</td>
<td>$52.87</td>
<td></td>
<td></td>
</tr>
<tr>
<td>#16 Frame and Sash Restoration</td>
<td>$60.24</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>$117.44</strong></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* No Cash Flow Projection Included in #2
**NCC Case Study #1**

**Project title:** Charron House Rehabilitation, Hull  
Casement Replacement  
**FHBRO:** Recognized, 52 points  
**Project No:** 8419  
**Contract amount:** $19,983.00  
**Year completed:** 1986  
**Glazing pattern** 3/3

### Cost Breakdown

The replacement cost did not include for the reconstruction of the interior window reveals and sills.

<table>
<thead>
<tr>
<th></th>
<th>Number of units</th>
<th>Cost breakdown</th>
<th>Cost per Unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame and sash replacement / casement/ dg / w / h</td>
<td>19</td>
<td>$16,986.00</td>
<td>$894.00</td>
<td>11.7</td>
<td>$76.41</td>
</tr>
<tr>
<td>Shutter replacement / h</td>
<td>9 sets</td>
<td>$2,997.00</td>
<td>$333.00</td>
<td>10.5</td>
<td>$31.71</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>$19,983.00</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend:**  
- s.g: single glazing  
- d.g: double glazing  
- w: weatherstripping  
- h: hardware  
- b: balance
### NCC Case Study #2

**Project title:** 142 St. Patrick Street, Ottawa  
Awning in lieu of storm and casement restoration  

**FHBRO:** Recognized, 54 points  

**Project No:** 9101  
**Contract amount:** $34,301.00  
**Year completed:** 1991  
**Glazing pattern:** 3/3

#### Cost Breakdown

A new awning window with an extended frame was installed in lieu of the original storm window and equipped with weatherstripping and hardware.

<table>
<thead>
<tr>
<th>Number of</th>
<th>Cost</th>
<th>Cost per</th>
<th>Avg. area per</th>
<th>Cost per</th>
</tr>
</thead>
<tbody>
<tr>
<td>units</td>
<td>breakdown</td>
<td>Unit</td>
<td>unit in sq. ft.</td>
<td>sq. ft.</td>
</tr>
<tr>
<td>Frame and sash replacement / casement / 10% of putty repair</td>
<td>11</td>
<td>$3,311.00</td>
<td>$301.00</td>
<td>22.6</td>
</tr>
<tr>
<td>Awning and Extended Frame in lieu of storm / d.g / w / h</td>
<td>11</td>
<td>$15,400.00</td>
<td>$1,400.00</td>
<td>22.6</td>
</tr>
<tr>
<td>Aluminum screen replacement</td>
<td>11</td>
<td>$1,100.00</td>
<td>$100.00</td>
<td>22.6</td>
</tr>
<tr>
<td>Exterior frame and sash restoration / single hung / w</td>
<td>21</td>
<td>$10,920.00</td>
<td>$520.00</td>
<td>19.3</td>
</tr>
<tr>
<td>Storm restoration / 10% of putty repair</td>
<td>21</td>
<td>$3,570.00</td>
<td>$170.00</td>
<td>19.3</td>
</tr>
</tbody>
</table>

**TOTAL** $34,301.00

**legend**
- s.g: single glazing
- d.g: double glazing
- w: weatherstripping
- h: hardware
- b: balance
NCC Case Study #3

Project title: 24 Sussex Drive, Ottawa
Frame and sash restoration
FHBRO: Classified, 80 points
Project No: RD 2620-4
Contract amount: $152,306.00 (estimate)
Year completed: Project on hold
Glazing pattern 6/6, 6/1, 8/1, 3/3, 4/4, 3/6, 2/2

Cost Breakdown

<table>
<thead>
<tr>
<th>Description</th>
<th>Number of Units</th>
<th>Cost Breakdown</th>
<th>Cost per Unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Removal of steel storm frame and sash restoration / single hung / 35% putty repair single hung / w / b / h</td>
<td>72</td>
<td>$4,660.00</td>
<td>$64.00</td>
<td>17.1</td>
<td>$3.74</td>
</tr>
<tr>
<td>Frame and sash replacement / single hung / double glazing / weatherstripping / hardware / balance</td>
<td>75</td>
<td>$51,800.00</td>
<td>$824.00</td>
<td>18.3</td>
<td>$45.02</td>
</tr>
<tr>
<td>Frame and sash replacement / single hung / d.g. / w / b / h</td>
<td>5</td>
<td>$15,180.00</td>
<td>$3,036.00</td>
<td>22.7</td>
<td>$133.74</td>
</tr>
<tr>
<td>Wood screen replacement / h</td>
<td>57</td>
<td>$19,950.00</td>
<td>$350.00</td>
<td>17</td>
<td>$20.58</td>
</tr>
<tr>
<td>Wood storm replacement / h</td>
<td>62</td>
<td>$36,456.00</td>
<td>$588.00</td>
<td>17.7</td>
<td>$33.22</td>
</tr>
<tr>
<td>Repair &amp; clean aluminum insert sash</td>
<td>124</td>
<td>$14,260.00</td>
<td>$115.00</td>
<td>9</td>
<td>$12.77</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>$162,306.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend:
s.g.: single glazing
d.g.: double glazing
w.: weatherstripping
h.: hardware
b.: balance
NCC Case Study #4

Project title: 541 Sussex and 25 George Streets, Ottawa
Frame restoration and sash replacement
FHBR: Recognized, 69 points
Project No: RD 2460-1
Contract amount: $157,041.00
Year completed: 1993
Glazing pattern 6/6, 2/2, 1/1

Cost Breakdown

The restoration work was limited to the window frame and did not include any work on the interior sills and window reveals

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Cost breakdown</th>
<th>Cost per unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame restoration and sash replacement / single hung/ sg / w / b / h</td>
<td>87</td>
<td>$137,025.00</td>
<td>$1,575.00</td>
<td>25.8</td>
</tr>
<tr>
<td>Frame restoration and sash replacement / casement/ sg / w / h</td>
<td>18</td>
<td>$14,616.00</td>
<td>$812.00</td>
<td>14.4</td>
</tr>
<tr>
<td>Frame and sash replacement / single hung/ sg / w / b / h</td>
<td>2</td>
<td>$5,400.00</td>
<td>$2,700.00</td>
<td>25</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$157,041.00</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
NCC Case Study #5

Project title: Rideau Hall - Minto Wing, Basement Floor
Single hung replacement

FHBRO: Classified, 91 points

Project No: 9027

Contract amount: $32,256.00

Year completed: 1991

Glazing pattern 2/2

Cost Breakdown

The single hung replacement windows with thermopane were designed with a full wood screen unit. The project also included all associated costs related to the interior window reveal restoration (replacement of 5 out of 12 interior sills and trims). GST was not included. GST was not included.

<table>
<thead>
<tr>
<th>Cost Basis</th>
<th>Number of units</th>
<th>Cost breakdown</th>
<th>Cost per Unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame and sash replacement / single hung/ d.g / w / b / h</td>
<td>12</td>
<td>$28,236.00</td>
<td>$2,353.00</td>
<td>19.5</td>
<td>$120.66</td>
</tr>
<tr>
<td>Wood screen replacement / h</td>
<td>12</td>
<td>$4,020.00</td>
<td>$335.00</td>
<td>19.5</td>
<td>$17.22</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>$32,256.00</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend:
- s.g: single glazing
- d.g: double glazing
- w: weatherstripping
- h: hardware
- b: balance
NCC Case Study #6

Project title: Rideau Hall - Minto Wing, Ground and Second Frame and sash restoration
FHBRO: Classified, 91 points
Project No: RD 2610-52
Contract amount: $35,263.00 (0% GST)
Year completed: 1993
Glazing pattern 2/2

Cost Breakdown

The cost reflects only the restoration work related to the windows themselves since there was no need to restore the interior window reveals. GST was not included.

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Cost breakdown</th>
<th>Cost per Unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame and sash restoration / single hung/ 100% putty repair sg / w / b / h</td>
<td>25</td>
<td>$35,263.00</td>
<td>$1,410.00</td>
<td>28.8</td>
</tr>
<tr>
<td>TOTAL</td>
<td></td>
<td>$35,263.00</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Legend:
- s.g: single glazing
- d.g: double glazing
- w: weatherstripping
- h: hardware
- b: balance
NCC Case Study #7

Project title: Rideau Hall - 1838, Minto and Hospitality Wings
Frame and sash restoration
FHBRO: Classified, 91 points
Project No: RD 2610-93 & RD 2610-94
Contract amount: $48,652.00 (0% GST and 5% work stoppage included)
Year completed: 1995
Glazing pattern 6/6, 1/1, 4/4, 8/8

Cost Breakdown

All double hung windows were modified into a single hung window with new balance and weatherstripping installed into the lower sash frame. The original weight cavity was then filled with insulation. Paint was removed entirely. The contract amount included 0% GST and 5% for work stoppage during construction.

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Cost breakdown</th>
<th>Cost per Unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame and sash restoration / single hung/ 100% of putty repair / sg / w / b / h</td>
<td>12</td>
<td>$13,733.00</td>
<td>$1,144.00</td>
<td>20.9</td>
</tr>
<tr>
<td>Minor restoration of casement / interior sill</td>
<td>1</td>
<td>$478.00</td>
<td>$478.00</td>
<td>35.7</td>
</tr>
<tr>
<td>Wood storm replacement / h</td>
<td>34</td>
<td>$26,315.00</td>
<td>$774.00</td>
<td>24.4</td>
</tr>
<tr>
<td>Wood screen replacement / h</td>
<td>35</td>
<td>$7,731.00</td>
<td>$221.00</td>
<td>13.2</td>
</tr>
<tr>
<td>Screen restoration</td>
<td>1</td>
<td>$734.00</td>
<td>$734.00</td>
<td>13.6</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td><strong>$48,652.00</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*legend*

s.g: single glazing
d.g: double glazing
w: weatherstripping
h: hardware
b: balance
**NCC Case Study #8**

**Project title:** 529 Richmond Road, Ottawa
Rochester House
Frame and sash restoration

**FHBRO:** Classified, 81 points

**Project No:** RD 2400-06-03

**Contract amount:** $34,510.00 (7% GST included)

**Year completed:** 1996

**Glazing pattern:** 12/12, 10/10, 2/2

**Cost Breakdown**

Hardware replacement was limited to new hinges only. No weatherstrippings were installed in this project. Paint was removed only where needed.

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Exterior frame and sash restoration / casement / 12% of putty repair / sg</th>
<th>Cost breakdown</th>
<th>Cost per Unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>36</td>
<td>$11,300.00</td>
<td>$314.00</td>
<td>20</td>
<td>$15.70</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Frame and sash restoration / casement / 12% of putty repair / sg</th>
<th>Cost breakdown</th>
<th>Cost per Unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>$1,930.00</td>
<td>$368.00</td>
<td>13.4</td>
<td>$28.80</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Storm restoration / 30% of putty repair</th>
<th>Cost breakdown</th>
<th>Cost per Unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>37</td>
<td>$18,755.00</td>
<td>$507.00</td>
<td>18.9</td>
<td>$26.82</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Wood storm replacement / h</th>
<th>Cost breakdown</th>
<th>Cost per Unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$517.00</td>
<td>$517.00</td>
<td>18</td>
<td>$28.72</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Screen restoration</th>
<th>Cost breakdown</th>
<th>Cost per Unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$84.00</td>
<td>$84.00</td>
<td>11</td>
<td>$7.63</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Number of units</th>
<th>Wood screen replacement / h</th>
<th>Cost breakdown</th>
<th>Cost per Unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>$1,924.00</td>
<td>$275.00</td>
<td>18</td>
<td>$15.28</td>
<td></td>
</tr>
</tbody>
</table>

**TOTAL** $34,510.00

**Legend**
- s.g: single glazing
- d.g: double glazing
- w: weatherstripping
- h: hardware
- b: balance
# NCC Case Study #9

Project title: Rideau Hall - 1906 and Minto Wings  
FHBRO: Classified, 91 points  
Project No: RD 2610-120  
Contract amount: $28,627.00 (0% GST and 5% work stoppage included)  
Year completed: 1996  
Glazing pattern 1/1, 3/3

## Cost Breakdown

<table>
<thead>
<tr>
<th>Description</th>
<th>Number of units</th>
<th>Cost breakdown</th>
<th>Cost per Unit</th>
<th>Avg. area per unit in sq. ft.</th>
<th>Cost per sq. ft.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame and sash restoration</td>
<td>6</td>
<td>$5,517.00</td>
<td>$919.00</td>
<td>14</td>
<td>$65.64</td>
</tr>
<tr>
<td>Storm restoration / 100% of putty repair</td>
<td>3</td>
<td>$1,620.00</td>
<td>$540.00</td>
<td>15.5</td>
<td>$34.83</td>
</tr>
<tr>
<td>Wood storm replacement</td>
<td>4</td>
<td>$1,613.00</td>
<td>$403.00</td>
<td>9.8</td>
<td>$41.04</td>
</tr>
<tr>
<td>Wood screen replacement</td>
<td>12</td>
<td>$1,721.00</td>
<td>$143.00</td>
<td>7.2</td>
<td>$19.90</td>
</tr>
<tr>
<td>Frame restoration</td>
<td>1</td>
<td>$141.00</td>
<td>$141.00</td>
<td>9.5</td>
<td>$14.84</td>
</tr>
<tr>
<td>Door, sidelights and frame restoration</td>
<td>1</td>
<td>$2,631.00</td>
<td>$2,631.00</td>
<td>47</td>
<td>$55.98</td>
</tr>
<tr>
<td>Frame and sash restoration / casement / single hung / casement / single hung / casement / single hung / casement</td>
<td>1</td>
<td>$981.00</td>
<td>$981.00</td>
<td>17.5</td>
<td>$56.05</td>
</tr>
<tr>
<td>Exterior frame and sash restoration / single hung / dg</td>
<td>5</td>
<td>$3,329.00</td>
<td>$666.00</td>
<td>16.7</td>
<td>$39.82</td>
</tr>
<tr>
<td>Frame restoration and doors, screens, transoms replacement / single hung / dg</td>
<td>1</td>
<td>$11,074.00</td>
<td>$11,074.00</td>
<td>74</td>
<td>$149.54</td>
</tr>
<tr>
<td><strong>TOTAL</strong></td>
<td></td>
<td><strong>$28,627.00</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Legend**  
- s.g.: single glazing  
- d.g.: double glazing  
- w: weatherstripping  
- h: hardware  
- b: balance
ALUMINUM REPLACEMENT WINDOWS: DESIGN ISSUES, PERFORMANCE, AND QUALITY CONTROL

David S. Patterson, AIA
Senior Consultant
Wiss, Janney, Elstner Associates, Inc.
Princeton Junction, New Jersey

Dennis K. Johnson
Consultant
Wiss, Janney, Elstner Associates, Inc.
Northbrook, Illinois

Joseph M. Walaszek
Senior Architect/Engineer
Wiss, Janney, Elstner Associates, Inc.
Northbrook, Illinois

The materials available for fabrication of replacement windows include aluminum, wood, polyvinyl chloride (PVC), and steel. Wood retains significant popularity for residential applications, and both wood and steel are used for certain historic preservation applications and can offer performance-based and cost effective solutions to window replacement. Though offering economic advantages, vinyl replacement windows have not been widely used in major restoration projects. Aluminum is perhaps the most extensively used material in the replacement window industry. Applications of aluminum windows range from residential structures to high-rise curtain wall facades, and from standard commercial units to highly-customized window systems.

Replacement aluminum windows offer the advantages of lighter weight, low maintenance, ease of installation, and may readily incorporate design enhancements to provide improved performance and aesthetics. New aluminum windows can completely replace existing windows, or can be fabricated with integral panning systems for installation over portions of the retained window frames. Aluminum can be readily manufactured in a variety of shapes and profiles, and can be finished in an almost endless variety of colors and high performance coatings or anodized treatments. The cost of aluminum replacement windows can vary widely depending on the complexity of the units and the types of features incorporated into the finished product; however, costs are generally competitive with other window alternatives.

Many factors must be considered prior to deciding what type of replacement window is most suited to a specific application. However, once the decision has been made to replace the existing windows with new aluminum windows, the critical window attributes must be designed and detailed to insure proper performance and aesthetics. Governing performance factors must be established for the replacement windows, including criteria for structural capacity, resistance to water penetration and air infiltration, and thermal performance. Specific design features must be addressed to assure performance, durability, and serviceability of the windows. The success of the window replacement system is largely dependent upon selecting properly designed and detailed windows and incorporating a sound quality control program prior to and during installation. The following discussion addresses performance criteria, design issues, and quality control measures particularly relevant to aluminum replacement windows.
Primary Design Issues

Structural Capacity
The determination of the expected local wind loadings should be the starting point in the selection of any replacement window system. It is necessary to establish the design wind pressures before establishing other window characteristics, such as depth and width of framing members, glass size, etc. American Architectural Manufacturers Association (AAMA) publications also relate resistance to water penetration and air infiltration to the design pressure of the window.

The American Society of Civil Engineers (ASCE) has established a standard, "Minimum Design Loads for Buildings and Other Structures," (ASCE 7-95) that defines design wind pressures. This document is a nationally-recognized consensus standard for evaluating wind pressures on buildings and structures, and provides information to calculate these pressures for windows as a component of the exterior wall. It is important to note that design wind load calculations are different for the components and cladding than for the main structural framing system of the building.

Wind pressures are based upon recorded 50-year mean recurrence intervals. Peak wind gust speeds (three-second duration), from which design pressures are determined, vary for different geographic locations across the United States but are typically measured to be 85 to 90 miles per hour. However, wind speeds in coastal regions can be as high as 140 to 150 miles per hour. Special wind regions, where unique or unusual wind conditions occur, also exist and require more detailed analysis. In addition, building configuration and local site conditions may necessitate a more thorough analysis.

The wind load values obtained from ASCE 7-95 define the wind pressures that a window must resist. Wind pressures are typically greater at the upper levels and corners of the building. These "high wind" zones are defined by the standard and vary according to the shape and dimensions of the building itself. Negative wind pressures are typically greater in these high wind zones, relative to the positive wind pressures for the exterior wall. These larger negative loads can result in the need for special reinforcement, supplemental anchors, or even the selection of a different window.

The ASCE 7-95 standard has been adopted or referenced by many national building codes, such as Building Officials Congress of America (BOCA). However, some building codes use different methods for determining pressures and may result in pressures that are higher or lower than those calculated from ASCE 7-95. The architect/engineer must decide which standard or method to use, as local building codes are often considered to be minimum requirements.

Design pressures can affect other aspects of the design. For example, structural requirements may preclude the use of aluminum when an aesthetic requirement for narrow sight lines (width of mullions and rails) is deemed necessary. An increase in design pressures may result in an increase in the size of framing members. This is particularly a concern in historic structures, where the desire may be to have the aluminum replacement windows fabricated to match original steel windows that were typically made with narrow sight lines, 1-1/2 inches or less, and designed for lower wind loads. Although lightweight relative to its strength, aluminum is not as strong as steel, often requiring larger profiles of framing members to resist the imposed loads. These larger profiles may be viewed as objectionable by designers. Balancing structural and aesthetic requirements may result in accepting compromise when neither the material nor the size of the framing members provides suitable choices. In this situation, the architect/engineer must resolve these issues with the owner.

Once the design pressure has been established, other resources can be referenced. The American National Standards Institute (ANSI) and AAMA have promulgated document ANSI/AAMA 101-93, "Voluntary Specifications for Aluminum and Poly (Vinyl Chloride) (PVC) Prime Windows and Glass Doors." This document includes primary performance requirements for various window types and grades, based upon calculated design pressures. This standard also references different grades of windows such as "R" (residential), "C" (commercial), "HC" (heavy commercial), and "AW" (architectural windows), and performance criteria associated with each of...
these grades. For example, an aluminum double-hung window for heavy commercial use bearing the designation DH-HC40 meets a design pressure of 40 psf. Similarly, an aluminum double-hung window for architectural use bearing the designation DH-AW40 also meets a design pressure of 40 psf. However, the deflection and permanent set performance requirements between these designations vary.

Water Penetration
Water leakage is one of the most common problems occurring in exterior wall systems today. Typically, AAMA recommends water leakage test pressures of 15 percent of the design pressure for all grades other than the architectural classification. For architectural windows, the water resistance test pressure is typically 20 percent of the design pressure. (AAMA formerly provided a separate performance standard for "architectural" or "monumental" windows in their publication GS-001, but this separate standard has now been incorporated into ANSI/AAMA 101-93. The designation "architectural," however, has not been clearly defined, but typically designates a higher-performing window.) For example, for a DH-HC40 window, as cited above, Section 2.1, "Primary Performance Requirements," of the ANSI/AAMA 101-93 specification allows no water leakage as defined by the test method at a test pressure of 6 psf. For a DH-AW40 window, the voluntary specification allows no water leakage at a test pressure of 8 psf.

Water leakage is typically defined by the American Society for Testing and Materials (ASTM) as water passing the innermost plane of the test specimen or through the corners of the test specimen. AAMA uses the term "water leakage" in much the same manner, but does provide for the accumulation of some water on stops or stools, as long as no damage occurs to interior finishes or treatments. It is important for the architect/engineer to define water leakage in the project specification to eliminate confusion.

Although AAMA provides ratings for classification of windows, the architect/engineer selects the test pressure suitable for the specific project. While industry trends suggest that higher water resistance test pressures will provide a better-performing window, similar problems related to water leakage in lesser performing windows are also found in higher-performing windows. The authors' field experience has shown that leakage problems with windows are typically not pressure-induced. Characteristics of window construction that are similar across window types, (i.e., window framing, joints, end dams, and sealant profiles), are the characteristics that typically cause leakage in the field. Leakage associated with these details typically occurs at test pressures of zero psf. Based on the authors' field experience, windows that meet a minimum water resistance test pressure of 6 psf to 8 psf typically do not have water leakage problems in the field if these other details are properly addressed.

Air Infiltration
Occupants of buildings with older windows are often conscious of air infiltration associated with drafts. With a replacement window, the architect/engineer has the opportunity to remediate or minimize this problem. AAMA considers air infiltration a primary performance issue. Typically, AAMA will test for the rate of air leakage at 1.57 psf (25-mile per hour wind speed) and 6.24 psf (50-mile per hour wind speed). The air infiltration values obtained from these tests can be used for comparing different window types, different window manufacturers, different features, etc. For operable windows, the performance is stated as air leakage in cubic feet per minute (cfm) per foot of sash crack. For fixed windows, it is stated as air leakage in cfm per square foot of window area.

Section 2.1, "Primary Performance Requirements," of ANSI/AAMA 101-93 provides criteria for maximum rates of air infiltration for different window types and classifications. For example, the maximum allowable rate of air infiltration for a DH-HC40 window is 0.37 cfm per foot of sash crack at a test pressure of 1.57 psf. A DH-AW40 window has a maximum allowable rate of air infiltration of 0.30 cfm per foot of crack at a test pressure of 6.24 psf.

Not surprisingly, the amount of air infiltration is generally greater through operable windows than through fixed windows. The air infiltration
The performance of the new windows can differ significantly from the original windows, and can affect heating, ventilation, and air conditioning performance requirements. Therefore, a mechanical engineer should be consulted regarding these aspects of the window design during the design development phase of the project. It is important to note that AAMA allows an increase in air infiltration of 1.5 times the specified rate for windows tested in the field.

Thermal Performance
One of the important developments in aluminum window design is the incorporation of improvement features such as thermal breaks into the aluminum window extrusion. A thermal break is a material of lower thermal conductivity that separates the interior and exterior sections of the main framing members in order to minimize heat flow through the metal window components. During manufacture of an aluminum section, a plastic material such as PVC or urethane is poured into a formed aluminum cavity contained in the extrusion. After the plastic material cools and solidifies, the aluminum is “debrided” (cut to create a discontinuity). The hardened plastic structurally links the two pieces of the aluminum section together and mitigates thermal transmission. While thermal break construction does improve the resistance of an aluminum frame to condensation formation, it can also foster new problems such as water leakage associated with thermal break shrinkage, sealant problems at the different material interfaces, shear strength of the hybrid sections, etc. Each of these properties must be carefully examined by the architect/engineer for a successful design.

One criterion used in assessing thermal performance of aluminum windows is the condensation resistance factor (CRF). The CRF is an especially valuable tool for assessing the thermal performance of aluminum windows because aluminum is a good conductor of heat. Since conductance results in the cooling of interior surfaces as heat moves from the building interior to the exterior, aluminum windows are susceptible to frost and condensation formation. To evaluate the condensation resistance of different aluminum window constructions, AAMA developed a test method to measure thermal transmittance and condensation resistance factors. This method is described in AAMA 1503.1-88, “Voluntary Test Method for Thermal Transmittance and Condensation Resistance of Windows, Doors and Glazed Wall Sections.”

The CRF compares inside and outside surface temperatures of the window and ambient air temperatures. Using design air temperatures and the dewpoint temperature, an appropriate CRF number can be identified. AAMA 1503.1-88 contains tables to assist the architect/engineer in the selection of the appropriate CRF for different exterior temperature and interior humidity exposures. The American Society of Heating, Refrigeration, and Air Conditioning Engineers (ASHRAE) has published data concerning design temperatures and expected interior humidity conditions for different regions of the United States. The CRF value varies throughout the United States based upon these different design conditions. For example, in the Chicago area, CRF values of 48 to 54 are typically required, while in Washington, D.C., suitable CRF values vary from approximately 42 to 50.

The “U-value” is the overall thermal transmittance of a window, as determined by testing in accordance with AAMA 1503.1-88. This factor is used by mechanical engineers to evaluate the heat flow (heat loss) or conductance through a window unit. As with condensation resistance, the U-value is important for metal windows because of higher conductance values. However, it is important to note that the glass infill may have a greater influence on the U-value for the window assembly than the metal frame due to the relative area of glass to metal. The U-values of various window manufacturers and types can be compared to obtain the most effective window type and construction for the particular application.

Aluminum windows can be glazed with a number of different materials, including monolithic and insulating glass. Insulating glass offers thermal advantages that monolithic glass does not, such as a lower U-value and improved condensation resistance. Insulating glass varies in its thermal performance. The units can be improved by using argon gas within the cavity or applying low-emissivity (low-e) coatings. Both of these treatments improve the U-value.
Although new aluminum window units can be designed and fabricated to accommodate any type of special glazing, the depth of the new units may be limited by the existing opening. Frame sight lines may also be increased to satisfy current "edge bite" requirements. If the new units are intended to match original units, the difference in depth and sight lines of the new unit may become a significant aesthetic issue.

The location of the window within the exterior wall can also affect the condensation and frost resistance of an aluminum window. For example, it is desirable to have a flow of heated air move across the interior window surface, rather than having the window isolated from the heat flow. Isolation from the heat flow can occur due to the improper location of the vents of the heating system or by installation of treatments such as draperies, etc. If the window is isolated from the warm air, it is more susceptible to frost or condensation, even with an acceptable CRF rating. It is also important to isolate the aluminum window components from adjoining metal construction. In masonry construction, where the window head is placed directly against steel lintels, a "short circuit" of the thermal break of the window system can be created. The presence of a cavity adjacent to the thermal break can also permit cold air to contact the interior portion of the aluminum window and reduce the effectiveness of the thermal break.

Other Considerations
Once performance criteria are determined, a decision must be made whether to replace the entire window unit or simply remove the sash and pan over the existing window frame. While complete replacement is preferred from a performance perspective, panning over existing frames is quite popular, primarily due to reduced labor costs and reduced disruption to the interior. Panning systems typically rely on sealant to keep water from entering the new system. However, most panning systems are constructed with poor sealant configurations that render the panning susceptible to water leakage. In the case of existing wood windows, prolonged water leakage can lead to deterioration of the existing wood framing members used to support the new windows.

Replacement windows must be anchored to various substrates in varying states of distress. It is therefore important to understand the condition of the existing components to which the windows are anchored. For example, where replacement aluminum windows are anchored to an existing terra cotta window surround, the integrity of the terra cotta system must be verified. Typically, terra cotta units have brick backup to which the new window units can be anchored, if the backup is sound. Also, if components of the original window are considered for anchorage, then the construction of these components must be understood and their structural integrity verified. If repair of the substrate is required, this must be completed before the new windows are installed. Where wood windows are being replaced with aluminum, it is possible to pan over and anchor into the existing wood window frame (if sound) after removal of the wood window sash. If anchors are to be installed into existing wood, it is important that the wood not be split during installation of the anchors, as splitting of the wood can compromise the structural capacity of the anchor. Where new aluminum windows are anchored into brick masonry, it is important to verify the adequacy of the masonry cladding to withstand the wind loads transferred by the window anchors.

Water leakage in window systems is often associated with framing joints within the window system, or with joints between individual window units that are linked together. A flashing or subsill is typically required to capture leakage at these locations and direct it back to the exterior. The subsill is an integral part of the aluminum window assembly that requires special consideration. In some manufacturers’ designs, the subsill must be penetrated with an anchor during installation of the window. The fastener location through the subsill is usually covered with sealant. However, movement can result in breakage of the seal, compromising the water resistance of the subsill. Also, it is difficult to access the seal for repair without taking the window assembly apart. It is therefore preferable to design a subsill so that the window can be installed without penetrating the subsill with fasteners. Subsills should also be
designed with mechanically-attached end dams and integral draining condensate gutters to help capture water.

Unlike subsills, flashings are not an integral part of the aluminum window system. Flashings need special consideration to assure that they are not penetrated by fasteners during installation. Three general categories of flashing materials are available: solderable, non-solderable, and polymeric. Solderable flashing materials, including copper, lead-coated copper, and stainless steel, enable a watertight seal to be made at the splice joints. These materials are usually more durable, allow the formation of drip edges, and permit replacement of adjoining sealants. However, solderable flashing materials are more expensive and more costly to install than the other materials commonly used. Non-solderable flashing materials include aluminum; however, special detailing is required to create watertight connections. In addition, aluminum is vulnerable to attack from cementitious products such as mortars. Polymeric materials include ethylene propylene diene monomer (EPDM), which is pliable and less expensive than metal flashings, but is also less durable.

For aluminum windows, the use of either aluminum or polymeric materials avoids contact with dissimilar metals and the risk of galvanic corrosion. Flashings need to be designed and installed to promote drainage. The flashing must be installed with a slope to the exterior to drain properly. It is also important to install terminations (end dams) at the ends of each window unit to prevent unwanted water from migrating into adjacent construction. Where flashings are used at window corners and materials are overlapped, there must be an effective seal at the intersection. A common error with flashings is the installation of an exterior sealant bead between the flashing and the window which prevents water from draining to the building exterior.

Sealants are an integral part of the window system and create the first line of defense against water infiltration. Although design of sealant joints is basic to window installation, factors in sealant joint design and sealant selection are often overlooked. The window manufacturer is typically only concerned with the window, the wall manufacturer is only concerned with the wall, and the architect/engineer may be caught in the middle. Important issues in sealant joint design are recognizing the sealant movement capabilities and preferred sealant configurations. For example, urethane sealants typically have 25 percent movement capability and an aspect ratio (width to thickness) of 2:1. Sealant must also have a proper surface with which to bond. To ensure that the sealant can accommodate the required tolerances, existing conditions should be carefully surveyed to determine the size of joints to be sealed. To provide a proper joint to seal, a gap of at least 1/2 inch should be maintained between the perimeter of the window and adjacent construction. Construction tolerances should be carefully considered and discussed with contractors to provide perimeter joints of 1/2 inch minimum width. Wider perimeter sealant joints also facilitate easier sealant replacement which is necessary because sealants typically have an anticipated service life that is less than that of the aluminum window. The entire perimeter sealant system of the window should be kept in a single plane to allow for easier and effective installation of the sealant.

The selection of sealants for aluminum windows is dependent on the bonding capacity of the sealant to the adjoining substrates. Silicone sealants typically have a better bond to metal than urethanes, and also provide excellent ultraviolet resistance. However, silicones may cause staining problems with adjacent substrates. New products such as "clean" or surface modified silicone sealant may help to overcome this problem. Urethane sealants can have good bond and less tendency to stain, but they are typically less durable than silicones.

One of the advantages of aluminum windows is the range of colors and finishes that can be applied to the surface. Some of the finish types include mill finished, anodized, solvent-applied organic coatings (such as polyvinylidene fluoride and siliconized polyester), and powder coatings. Anodizing the application of a dense, oxidized layer to protect the aluminum surface, has a long history of service. However, color matching and alteration of surface appearance may be long-term problems on existing buildings. The application of powder coatings to aluminum
windows has a shorter history of use than other coatings. Powder coatings, which are not solvent-based, will likely become more popular with the widespread implementation of volatile organic compound (VOC) restrictions. Although some powder coatings may have a slightly shorter service life, they are relatively easy to recoat compared to current high performance fluoropolymer coatings. Siliconized polyesters, while more expensive than some other polymer systems, provide excellent resistance to fading and chalking. The success of all coatings and finishes depends on the surface preparation of the material and the adherence to sound application practice. Each finish introduces a unique problem for sealant applicators and must be analyzed to determine appropriate sealant techniques.

Quality Control

Many thoughtful designs have been short circuited by windows that did not live up to manufacturer’s performance claims or by improper installations. One of the primary reasons for premature window failure is lack of proper quality control prior to, during, and after the installation of new replacement windows. Selection of the most appropriate, proven, replacement window followed by careful attention to detail does not insure a trouble-free installation without proper quality control measures. Quality control measures that should be given consideration in any replacement project include laboratory and field mock-ups, field testing (air infiltration, water resistance, and sealant performance), and in some cases, structural proof loading.

Laboratory mock-ups allow the architect/designer to confirm manufacturer’s published performance data and to review the constructability and the aesthetics of the installation. If the proposed replacement window is a discrete standard size (close in dimension to that tested by the manufacturer), and interface details are not unique or unusually difficult, the laboratory mock-up may be waived if the manufacturer offers test data by an independent testing lab supporting performance claims. Accompanying this data should also be an accurate description of all sealant installations for verification in the field. However, whether or not a laboratory mock-up is performed, a field mock-up of the new window installation is always recommended. The field mock-up allows the designer to review constructability, aesthetics, and performance of an actual installed window system as well as review and verification of the installed sealants.

As noted above, water leakage is a common problem with exterior wall systems. Standard test methods have been developed by ASTM and AAMA to verify the performance of installed windows and curtain walls. Field tests to evaluate water resistance performance include ASTM E 1105-90, “Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Curtain Walls, and Doors by Uniform or Cyclic Static Air Pressure Difference;” AAMA 501.3-83, “Field Check of Water Penetration through Installed Exterior Windows, Curtain Walls, and Doors by Uniform Air Pressure Difference;” and AAMA 501.2-83, “Field Check of Metal Curtain Walls for Water Leakage.” ASTM E 1105 and AAMA 501.3 are similar and involve the application of a uniform spray of water at a minimum rate of 5.0 U.S. gallons per hour per square foot at the exterior of the test specimen, while a static air pressure difference is induced across the test specimen. The test is performed for a specific period of time during which the interior is monitored for water leakage. Water leakage is defined by each test method. While AAMA will allow small amounts of water leakage during the test period, ASTM allows no uncontrolled water to pass the innermost plane of the test specimen. The designer should be well acquainted with these test methods and determine which method is most suitable for the project. AAMA 501.2 is designed to test non-moving joints within a window, door, or curtain wall system. This test method utilizes a water spray from a specified nozzle delivered at a pressure of 30 to 35 psi. During this test, approximately 5 ft. of joint is tested for a 5 minute test period, or one minute per foot of joint. Again, the interior of the test specimen is monitored for water leakage during the test period. This test method is also quite useful in pinpointing the location of water leakage as long as unencumbered visual access to the interior of the test specimen is possible. If visual access is a problem and adjacent absorbent building

Window Rehabilitation Guide for Historic Buildings III-35
materials exist, then alternative test procedures may be advisable. Structural performance can also be verified during the field mock-up by proof loading the installed assembly.

Field testing should not stop with the successful completion of the field mock-up but should continue at the beginning and throughout the course of the project. This testing is most useful if performed early in the project when it is possible to address problems which may develop during the full scale installation process. An ongoing field testing program should include random water resistance testing in accordance with ASTM E 1105 and AAMA 501.2 (described above), and sealant peel adhesion testing. Since sealant has become an integral component of window and curtain wall systems, its proper placement, profile, and installation is required to assure long term performance. During the installation of the replacement windows, quality control measures should be implemented to insure that sealant is installed in accordance with the manufacturer's instructions with particular attention to surface preparation, priming (if required), placement, and tooling.

Proper selection and design of replacement aluminum windows, followed by attention to detail and implementation of well defined quality control program provide insurance for a successful window replacement project.
Replacing Steel Windows with Steel Windows: Crosley Estate/Seagate, Manatee County, Florida

Linda D. Stevenson, AIA
Stevenson Architects, Inc.
Bradenton, Florida

Introduction to the Building and Project

The Crosley Estate is a two story, Mediterranean Revival style residence, built in 1929 as a winter home for the American entrepreneur, Powel Crosley. Situated on the east side of Sarasota Bay, the house was designed to allow for maximum ventilation through the interior spaces. The property served a residence until 1982, when the house was sold to a development company. When regulatory changes made the planned development of the property unfeasible, the property was acquired by the Manatee County government in 1991. Several phases of restoration and renovation work have occurred in the last five years. The building’s Preservation Plan identified those features relating to the weathertight integrity of the building as the first priority of work. Last year, the clay tile roof was restored, and the windows and doors were restored and replaced. This work was performed with the assistance of a grant from the Florida Department of State, Division of Cultural Affairs, called the Cultural Facilities Program (Figure 1).

The Mediterranean Revival style was first popularized by Addison Mizner as an architectural expression of the new paradise that was Florida. By the 1920s, the style was commonly used on residential structures throughout the state, on both small and large houses. Typical features included stucco walls, clay barrel tile roofs, decorative motives borrowed from Italian, Spanish and Moorish architecture and steel casement windows and doors (Figure 2).

The Crosley/Seagate mansion was constructed with commercial grade materials. The structural system was a steel frame, with steel bar joists supporting a metal deck and concrete slab floor system. Exterior and interior walls were built from hollow clay tile units and brick over the arched openings. The exterior was covered with stucco; the interior with plaster. These elements helped determine some of the design decisions made in the course of the window project.

The building’s fenestration system consisted of 84 residential type steel casement windows and six French doors, as well as three wood windows and exterior wood doors. The window designs have either single or paired ventilating casement sash. Some units featured elongated arch topped transom units. The original window design was made from hot-rolled steel Z-shaped sections, with a 7/8 inch to 1 inch profile dimension. The window units were fastened into the exterior face of the original wood bucks that framed the rough masonry openings. The exterior stucco was then applied over the bucks and struck off at a sharp angle all around the opening. The interior plaster work was a three coat system over expanded metal lath and was either held off the masonry wall on a metal channel frame system, or in some areas, directly plastered to the masonry wall. In either case, the plaster corners were radiusede and carried into the window openings to the frame section. The original glazing was high quality, single strength, 3/32 inch thick sheet glass. The original finish system appears to have consisted of a primer and one coat of a “grass” green paint color.
A unique feature of the original installation was the incorporation of rolscreens into the head section of the window units. The arched units had the rolscreens fastened to the transom bar, the flat head units had a pocket built up into the wood framing above to recess the metal housing. These elements had been removed from almost all of the openings by the former owners, but a few examples remained in place.

Design Problem

Environmental factors had resulted in the deterioration of the steel windows and doors. Located adjacent to a body of salt water, subject to fierce storms and hurricanes and strong ultraviolet rays, the original green paint coating had disintegrated on most units. The exposed steel was rusted and badly corroded; some of the muntin bars and sill members were reduced to crumbling sections. This deterioration was aided by the design of the Z-section, which had a small raised lip that held the glazing putty in place. This lip also served to trap water in the section at horizontal members. Four of the window units were in good condition, these windows were located inside the first and second floor west porch areas, protected from the sun and the rain. The building was vacant and subject to vandalism for an extensive period, and many of the glass panes were broken.

Planning

Each window and French door was catalogued and measured, and the existing condition of each opening was assessed by the architects in the design phase of the project. Detailed, measured drawings of each window type was made.

Research on the various replacement options was conducted. Aluminum replacement units were studied; however, the original profiles of the steel sections could not be maintained. Another option was a steel window system with aluminum glazing clips. However, this design afforded no opportunity to reproduce the effect of putty-glazed sash. Steel casement windows that were almost perfect duplicates of the original windows were found in the residential series made by A & S windows. Based on the availability of this window and on the extent and severity of the deterioration of the existing windows, it was determined that the best course of action would be to replace the windows.

Window Design

The new windows correspond almost exactly to the size and configuration of the original windows. New window sections are constructed from hot-rolled, solid steel bars. The frame and sash members are Z-sections, approximately one inch in thickness. A few minor design variations from the original design were incorporated into the production of the windows. The new windows were designed to be 1/4 inch smaller in both height and width, to facilitate placement in the existing openings. The transom bar was made from one piece of steel instead of two, but their visual appearance is the same as the original design (Figure 3).

Due to the aggressive marine environment, the specifications called for a hot-dipped galvanized coating on the windows. This process required that the previously assembled units of ventilators and frames be shipped to the galvanizer, taken apart and treated. In order to identify the related window sections post-treatment, an identification system of different sized steel washers on steel wires was used. The violent nature of the galvanizing process tends to warp the frames. After this process, the window frames and sash needed to be straightened and re-assembled, a labor-intensive process (Figure 4).

Standard specifications called for shop-priming the windows. However, in order to ensure compatibility with the proposed finish paint system, the design team elected to field prime and paint the windows.

Installation and Scheduling

The project schedule had to accommodate a special event planned for the Crosley Estate, which occurred in the middle of the construction period. The production schedule required about 16 weeks, so a temporary enclosure system of plexiglass panels on wood frames was devised and installed for the duration of the project.

The installation system had to be modified from the original construction. Originally, the windows were installed on wood bucks placed in the rough
masonry opening, the stucco was then applied to the exterior of the building, sealing in the frames. After removal of the units, the existing wood bucks were inspected and were replaced with pressure-treated wood where rotted or damaged.

Modification of the clip design that held in the frames allowed for installation of the window frames without disturbing the stucco. The clips were z-shaped and fastened into the side of the wood buck. Plaster was then applied over the bucks and terminated at the frames, thereby hiding the clips (Figure 5).

New 1/8 inch float glass panes were installed. The glazing compound used was a gray glazing putty. The windows were set into angled frames and the glazing was hand applied, then struck off. The glass was held in by copper coated wire u-clips, two per side of each pane of glass (Figure 6).

The openings were caulked with a one-part polyurethane, the color selected was in the range of the stucco color.

The environmental conditions also determined the selection of finishes. The paint system consisted of a recoatable epoxy primer and two coats of high-solids polyurethane paint. The primer had to be applied by brush. The finish paint coating was applied with a sprayer in two coats.

The existing cam handles on the casement units were re-used. The brass handles were cleaned and coated with a lacquer polish (Figure 7a). The French door handles were salvaged form the original doors, repaired and re-used (Figure 7b).

Costs

The window restoration project was completed for $244,000. The project was let for competitive bidding, with the requirement that the contractor have previous experience in this type of project.

Notes


Bibliography


Other Sources

Shop Drawings by Key Glass & Window, Inc.

Project Team

Owner: Manatee County Board of County Commissioners
Bradenton, Florida

Architect: Stevenson Architects, Inc.
529 13th Street West
Bradenton, Florida 34205
Contact: Linda D. Stevenson, AIA

Contractor: Willis A. Smith Construction, Inc.
2902 Hyde Park Street
Sarasota, Florida 34239
Contact: David Sessions, Vice-President

Window Contractor: Key Glass & Window, Inc.
9107 64th Avenue East
Bradenton, Florida 34202
Attn: Greg Burkhardt, President
Figure 1. East elevation of the Crosley Estate.

Figure 2. French door with arched transom.

Figure 3. Transom detail.
Figure 4. New window units in manufacturer’s workshop.

Figure 5. Drawing of jamb detail.
Figure 6. Window glazing on site.

Figure 7a. Restored window cam handle.

Figure 7b. French door - cremone bolt hardware.
Designing a Replacement Window to Fit Your Needs

Richard Graf
President
Fort Point Consulting, Inc.
Somerville, Massachusetts

Introduction

Window systems are usually designed by manufacturers, typically in response to a perceived market need or as a result of technological advances that make new materials available. This paper is about a more rapid form of evolution—the window system invented during the development period of a project specifically for the needs of that project.

As an owner, I have presided over the invention of two historic replacement window systems during the development process. The systems replicated both steel and wood sash with true divided light systems constructed of aluminum. (These windows are documented in Windows Tech Notes 12 and 18.) The process of developing these windows under the press of a tight schedule utilized every skill which I have acquired during a wide-ranging career: building techniques, architectural history, business acumen, diplomacy, and team leadership. These skills were used to introduce the possibility of invention in the window selection process to the renovation planning for the Pentagon.

In 1994, during an intensive two-day seminar with the team assigned to renovate the Pentagon, I advised on the myriad activities needed to include the possibility of invention in the window selection process. This paper grew from that seminar and is about the mode of thinking which allows the possibility of going beyond known window systems. It is not, despite the temptation to dwell on actual battles fought, a retelling of case examples. This paper presents that approach to window system evaluation and selection.

It should be understood that my approach is that of a builder/owner—not an inventor. In other words, the decision to go “custom” with a window system is a final choice, not an initial decision. The process of finding the best window replacement solution must, therefore, begin with research into all potential alternatives. I know of no honest way to invent a new system short of arriving at a point where nothing available will properly solve the problem at hand. This lack of a known system must also be coupled with a believable hypothesis that a better solution can be engineered and produced on time and on budget.

The process begins as an open-ended exploration and in most cases leads to selection or modification of an existing system. When an invented or “custom” system is judged to be the best solution, the process abruptly becomes a teleological exercise where the final product is known and all activities must be directed towards getting that product through manufacture, testing, shipping and installation. This paper sets out guidelines for owners to follow as they move from the beginning to the end of the process, recognizing that few will actually pass into the custom production phase.

Before going further, it is useful to describe “custom.” In this context the term describes a window that incorporates invented or recreated profiles and invented or recreated manufacturing...
processes. Excluded from this definition are systems which just change face dimensions, since almost all historic renovations require this basic adjustment. Customizations range from minor, new extrusions to match a special brick mold, to major, entire systems including new shapes, uses of materials, new ways to achieve thermal breaks, etc.

At the extreme range of customization would be the production of a new rolled steel profile, a process requiring retooling of a rolling mill. Given enough pressure from a large enough project with a big enough budget, even this degree of customization is possible because generally speaking, the larger the project, the greater the potential for customization. That this flies in the face of prudence, since one would ideally test the most extreme modifications on something small rather than something large, forms the basis for the discussion that follows. Customizations are not entered into lightly.

The Research Phase

During the research phase of the window design process the owner has to manage three critical operations which are central to ensuring that any window system, whether ready made or invented from whole cloth, is successful.

- Team assembly
- Setting technical, historic and budget goals
- Evaluation of alternatives

It should be up to the owner to select the team, including architect, historic and technical advisors, and contractor. Ideally, this team should be assembled at the beginning, even at some extra cost to the owner’s budget. Attributes of good team members are listed below.

A window/facade expert - Any sizeable project should hire a consulting firm with technical engineering skills. This team member will prove invaluable as an interpreter of arcane codes, developer of specifications, skeptic about effects of time and weather, expert on technical details and materials, evaluator of test data, inspector of manufacturing facilities, and observer of installation.

Architect - Ideally, the architect has a large working knowledge of historic window repair and replacement. Technical knowledge and attention to detail are paramount, and the architect should be in charge of organizing and distributing the documentation regarding possible systems. The architect has the ultimate responsibility for specifying and approving the windows, and has to be very involved in the process. It has been my experience that design of custom windows is not something that comes easily to most architects due to constraints of time, fee, and liability. Hence, there is a need for the owner to augment the team with consultants who work directly for the owner and who can assist the architect.

Historic consultant - The historic consultant provides more than just knowledge about buildings. He or she should also have in-depth knowledge of what has been approved in the past and what is likely to be approved in the future by reviewing bodies. Input from this consultant can help the team emphasize areas of research that it may not wish to pursue, and conversely, leave behind solutions which are unlikely to meet with approval.

Contractor - The contractor must have the capability to assist in the research phase and potentially the custom production phase. Attributes needed in both are a willingness to price alternatives, and a willingness to let the other team members meet with and talk to subcontractors and suppliers. The builder should assist in enforcing technical specifications. At times in the process, the builder may need to adjust the schedule to wait for the window design team. As the research often leads to just one product, the builder will be the point person for what amounts to a negotiated - rather than a bid - window contract.

The team must invest time in determining the technical, performance and cost specifications that would apply to any window system that you might use. This information should be assembled up-front, as opposed to being stumbled across as the process evolves. Major components of the specifications include the following:
Determine the geometric characteristics - This requires determination of the proper historic period of significance. Replacement window dimensions must conform with key components of the historic windows. The historic consultant should help the architect in setting and negotiating these standards with review authorities.

Determine exposure classification of building - Exposure has to be considered in light of localized conditions. Pay attention to unusual circumstances, such as coastal exposures, wind “alleys” in downtown locations, etc. Sometimes problems at severe spots (corners up high, for instance) can be solved separately, and there is no need to make all windows meet the most extreme criteria. However, any window that does meet the most extreme criteria is likely to perform very well in the less exposed locations. Remember that water travels sideways and upwards during storms. Air pressure differential can pull water into the window system during severe weather. Leaks create irrefutable evidence that any occupant can and will notice.

Decide about operability - What is the code stance of the building? Is operability required for fresh air requirements? Does the mechanical engineer want you to forgo operable windows? Do the occupants want operable windows? Is the provision of fresh air in new ventilation systems an adequate replacement for the air which the old windows were introducing? Are operable windows adding value to tenants, guests, residents? Do operable windows get any favorable consideration from fire or building departments, such as relaxation on requirements for expensive components like smoke exhausts?

Decide about thermal and infiltration performance - To what standards of infiltration and thermal resistance will all contending products be held?

Determine the effect of interior moisture on the windows - Some environments are very humid and adversely affect storm systems that are not tightly sealed. Some custom systems sacrifice thermal break perfection for dimensional accuracy, but in a very moist environment cold metals can mean dripping or icing on the interior.

Decide about glazing type - Does the glazing need to be insulating? Do you require low-e glazing? What are the sight lines of the spacers used in double glazing? What color should the spacers be?

Decide about noise transmission - Sometimes codes determine the degree of sound attenuation that a system requires. In any case, user comfort must be addressed, especially in residential and hospitality uses.

Determine code stance regarding flammability of window materials - Some codes and some fire areas in cities do not allow wood, for instance.

Decide the longevity and degree of maintenance that you require - Do you want 30, 60 or 100 years of life in a window? Are you willing to go through frequent maintenance cycles with paint, sealants and glued-on trim? Aluminum windows have enjoyed a reputation for near “eternity,” but no applied finish is forever, and thermal breaks made of plastics are beginning to fail in some cases. In one case, we moved to replace totally disintegrated wood and putty with aluminum, knowing that the ultimate winner in longevity might be new wood, but that for the next three decades we would have virtually no maintenance with aluminum.

Determine the cost range - What can you afford? Know your budget from the owner’s and the contractor’s points of view. Make sure you understand where the window items reside within the construction budget. “Windows” might include the window unit itself, exterior sills, window installation (ironworkers, carpenters), glazing, caulking, interior trim, interior sills, painting, etc. Do all of the potential window systems require all of these trades, or do some do double duty by eliminating items? This is a way to sometimes justify additional window expenditures. Calculate expenditures on upkeep and painting. Maintenance savings can justify a larger initial cost in some situations.

The owner must spend time and money to investigate the alternative window systems available. It is imperative to start with the assumption that something existing will suffice. An experienced team has a running start, of course, with libraries and specialists in place.
Unless the team is fully up-to-speed from recent research on similar projects, it pays to thoroughly research the possibilities. Products change, performance information becomes available, locales are different, historic standards evolve and vary from place to place, etc. Technical, aesthetic, budget, and historic information is all equally important.

Check the existing literature exhaustively - Research all systems that appear to answer the need. A good architect should have catalog information, tech notes, magazine articles and detail libraries available.

Meet with window salesmen - Discuss their available products, their potential modifications, and the assets and drawbacks of their competitors. Reconfiguring or mildly modifying something existing has to be considered. Use salesmen as participants in creative thinking, but let them know that you are investigating parallel paths. Resist the temptation to “go steady” too early as it could leave you in an unhappy marriage later on.

Learn all you can about the existing windows - Look for the original manufacturer, since the old dies, jigs, blades, templates, etc., may still be around. Check for name plates and labels. Manufacturers can sometimes be coaxed into retooling or modifying an old system.

Make restoration of existing windows a sincere option - Imagine all those windows, all that antique glass, in the dumpster. Look into cost of labor to restore and availability of specialists. Look into replacement of parts of systems. Is it possible to keep exterior wood trim and brick molds? Is it possible to replace the sash only?

Can you add a layer? Would storm windows on either the exterior or interior be acceptable? In some applications and localities they are fine. For example, some local review boards in Vermont have, on occasion, considered storms as an acceptable exterior modification to wooden sash. Consider humidity levels in the building when investigating partially sealed systems such as storm sash.

Check references on all systems under consideration - This is a good way to get candid information from building owners and a good way to understand what you really want. If a component seems technically adventurous, be very inquisitive about its performance. Items such as applied muntin grids, glass which cannot be removed without destroying expensive components, new types of balances and tracks, and substitutes for standard methods of glazing are all worthy of intense scrutiny.

In most cases the research phase identifies an acceptable product that can be used as is or with minor modifications that fall within the manufacturer’s tested and guaranteed product lines. Given the many conflicting demands of historic window replacements, there is not always a great existing solution.

Systems Which Break New Ground

At some point in the process of evaluation, the team may hypothesize a system that does not currently exist, thus beginning the process of invention. The windows may be too deteriorated to restore, yet accurate replacements may be too expensive to buy, too expensive to maintain, or simply gone from the scene, like many older steel sash systems. Near approximations using the systems which turned up during research may leave architectural review board members, and the team, lukewarm or positively turned off. But while considering the temptation to invent something new, it is imperative to select the better of the existing systems for detailed study and costing and to proceed with this as a back-up even while looking for a creative alternative.

Moving beyond the manufactured systems requires a certain leap of creativity. In one case, study of shop drawings for skylight glazing led to a 1-1/16 inch thermally broken muntin bar that would accept, and tightly grip, 5/8 inch insulating glass. This system, described in Tech Note 12, departs from existing window assemblies, and borrows from roof glazing technology in its use of a continuous screw boss and intermittent screws to clamp the inner and outer aluminum extrusions together. One of the design freedoms that our experts allowed was the forgiveness of minor thermal “short circuits” where the metal screws joined the inner and outer extrusions.
Another incentive to the invention of this particular system was the Boston Fire Department. In lieu of smoke exhaust for the huge 70,000 square foot tenant floors, firemen needed to be able to break windows from the ground. This requirement ruled out applied muntin grids, which at the time were the only existing system that we could afford that gave the appearance of steel industrial sash. The firemen did not want them falling from above. We were left without an affordable system as the cost of replication steel sash was not affordable on our tight budget.

In the case of the other major invented system in which I participated, we were determined to avoid the continuous painting of 12-over-12 wood sash on a 700,000 square foot historic mill complex. No aluminum systems with applied muntins over insulating glass retained the building’s historical character in such a critical location. A true divided light 12-over-12 made of aluminum seemed to be the answer, but individual insulating light were out of the question, as muntins could not exceed 5/8 inch in width. The creative solution contained real divided lights in aluminum muntins with an inner storm panel. Paint and putty were eliminated by the use of a solid aluminum muntin which replicated the putty profiles of the originals. Borrowing from the plastics industry, muntins of extruded vinyl snaps over the aluminum on the inside to replicate the profile of the existing wood. The final system, described in Tech Note 18, also incorporated new extrusions for sash rails and an inner storm sash that rides on each sash piece.

The invented systems were introduced by a series of sketches and informal meetings between the owner and the architect. The ideas at first seemed subversive and intrusive upon an orderly process. Communication with the window subcontractor and ultimately with the manufacturer allowed feasibility and pricing to be checked. Communication with the window/facade expert kept the specifications in force, and raised questions about...
construction and performance. The systems were designed to "weep" any infiltrated water through the web of muntins, into the sill, and out through the weep holes. Sealant technology and cost of application, especially on multi-pane units, were topics discussed at length with facade experts and the manufacturer. In issues of cost versus reliability the owner relied upon the opinion of the window/facade experts.

In both cases, since the systems did not exist, drawings had to be done to a high degree of accuracy to satisfy both the manufacturer and the reviewers before the windows could be seriously considered. This took place primarily within the architect's and the manufacturer's offices and required constant communication and the cooperation of the contractor and subcontractor.

Because of the scale and the sensitivity of the projects, full-scale mock-ups were made in wood and inserted in actual openings for inspection of profiles and color. Approvals were granted with the proviso that the final metal pieces exactly match the accepted mock-up. System costs were locked in place based on the approved drawings, mock-up and specifications.

The custom process then enters a teleological phase in which all actions must lead directly to the defined end product. Failure is not an option, nor is any protracted period of wandering. The process has to proceed with virtually no flaws and must adhere to a rigid construction schedule.

Any major departure from existing products must be lab tested before it is put into production. Tests require the actual final components – in our case, aluminum extrusions. The extrusions begin with drawings, approved by review boards as to profile, and approved by the engineers as to strength, drainage channeling, etc. The drawings lead to machined dies, but tooling the dies right is an art that can take time and several adjustments. Some of the shapes required thermal breaks, a complicated bit of engineering in which metal is milled away and replaced with molten plastic, allowing more room for error.

Making the dies and pulling the extrusions are separate specialties, located wherever the manufacturer finds them. In our case extrusions came from the Pacific Northwest, were assembled in...
Denver, and then shipped to Dallas for testing. Even at full speed, the process of getting extrusions made, machined and assembled by the window manufacturer, and shipped to the testing lab consumed all the time available before production was scheduled to begin. The testing itself involved intense air pressure differentials and driving sprays of water that severely bowed the large window units, forced water into any tiny opening, and generally created extreme tension on the part of the window team as well as the window. Representatives from all parts of the team were present, and all had roles to play.

The requirement that testing utilize the actual production components leaves no time for re-engineering the system. Perhaps in a perfect world there would be time to turn back without penalty. In most construction projects, however, the clock is ticking expensively and if customization slows progress, delay costs will be assessed to some party.

The lack of time to correct major errors does not mean that adjustments cannot be made, but it does mean that if testing reveals major design flaws the entire process may have to be abandoned and a back-up substituted - highlighting the reason for researching, pricing and maintaining another viable system.

Pressure from all parties that the test not fail underscores the need for true technical experts to assist the owner in interpreting the test results, to observe the tests in person, and to recommend modifications if they are required. Modifications made to the system as a result of testing may have to be incorporated into production without the luxury of another full-scale test. Most projects that can afford the cost of developing a custom window system are large, and even small decisions can have major impacts.

Following successful testing and de-bugging of the system, the process still requires intense involvement from the team. The contractor is under a great deal of pressure, but is also relieved of some responsibility for delays and overruns by the fact that the owner and architect have introduced variables into the system. One of the chief jobs of the owner is to maintain the contractual price of the window system when confronted with attempts to increase it. The key line of defense here is laid down when the window performance specifications are written at the beginning of the job. The supplier should own a window system that performs properly over time - allowing the owner to insist on high quality hardware, glazing and sealant materials with no extra cost to the project. The team has to be on a constant look out for potential design flaws, not only in the manufactured windows, but also in their installation techniques and ancillary systems such as sub-sills, trim, etc. A new system will be presumed guilty until proven innocent, so it pays to observe window insertion, especially if using separate trades for installation, and when adverse weather conditions may compromise workmanship.

The final results should be less than spectacular, in the true spirit of historic renovation. Our highest praise for the window replacement system was that it was impossible to tell what was wood and what was aluminum, even when both were side by side.

In my experience the process has proven to be gratifying on a number of levels. Advancing building technology is one level. Adding to the ways to adapt historic buildings for new uses is another. In our case, finding real divided light solutions and eliminating the need for false appliques advanced the cause of architectural integrity. Producing a finely detailed and designed system also gives a sense of pleasure, and of course, there is nothing like working on a complex project with a dedicated team to lend a sense of purpose and of excitement. Buildings are not just for future generations and current users, they are also for the people who put their lives into getting them built.

Notes

SPECIFYING WOOD WINDOW REPAIR AND REPLACEMENT

William G. Foulks
Associate
John G. Waite Associates, Architects, PLLC
Albany, New York

Specifications for the restoration of wood windows and for new wood windows are part of the process of quality control required to ensure that, at the completion of a restoration project, the windows comply with project requirements. The specifications seldom stand alone. Usually, they are part of a total quality control package, which may also include a window control survey (to determine the condition of the windows and the work required), drawings (that show the extent of the work and configurations of replacement windows), and a window schedule (to outline the work required on each window or on each type of window).

The levels of both the specifications and the total quality control package vary with many factors affecting the project including:

The significance of the building: whether it is a National Historic Landmark of significant stature on which all remaining original building fabric should be preserved or whether it is an important part of a streetscape in which preserving the forms of the elements is most important. The building's significance can affect the balance between the retention of original materials and forms and compliance with current thermal performance standards and also how closely historic elements are replicated.

The condition of the windows: Wood window restoration can cover all conditions from windows that require little more than glazing putty replacement, preparation, and painting to windows that require extensive repairs of wood members, hardware replacement, and even the replication of one or more sash.

The type of client: whether it is an individual owner or a government agency. The type of client affects the selection and level of control possible over the craftspeople doing the work.

The scope of the project: whether only the windows are being restored and replicated or whether the window restoration is a small part of the total project.

The scale of the project: whether there are several windows, several hundred windows, or several thousand windows to be restored.

This paper discusses specifications for the restoration of existing wood windows and for new custom wood windows to replicate existing windows. Windows from commercial wood window manufacturers, which, when their configurations and profiles are appropriate, can be used as replacement windows in some historic buildings, can be specified using edited wood window sections from master specifications such as those published by the American Institute of Architects (AIA) and the Construction Specifications Institute (CSI). The following text concentrates on the specification information required to ensure the quality of the restoration work and not on more general information that might be found in similar specification sections specifying standard wood windows.

The form in which the information is presented should follow the industry standards promulgated
by the Construction Specifications Institute. Under the CSI's 16 Division format, specifications for wood relating to wood windows are found in Division 8 with section numbers in the 08610s. On a project consisting only of window work, most of the required information might be contained in these technical window sections. On larger projects, these sections might outline the work on the windows and reference other sections for requirements of specific restoration procedures, such as wood consolidation, member replacement, and glazing, that are also used in other project work.

In addition to the technical sections — the window sections and those specifying related work — other parts of the Project Manual, including the Bidding Documents and Division 1 specification sections, can provide requirements that affect the quality of window restoration work. The requirements discussed below should be integrated into the CSI section format.

Setting the Standard

To obtain the best work, the entire quality control package, including the specifications, should reflect care and knowledge on the part of the architect or specifier. Although in the best of circumstances (experienced craftspeople working on a time and material basis), notes on the drawings indicating that the windows are to be restored might be sufficient, it is best to indicate in the contract documents that the specifier is thoroughly familiar with the windows’ existing conditions and with other factors affecting the work.

When specifying window restoration, appropriate terms such as conservation, preservation, and restoration should be used throughout the Project Manual to indicate that the level of work expected is higher than rehabilitation. In the Division 1 Section “Scope of Work,” which summarizes the work of the project, the significance of the building and the required quality level of all project work should be emphasized.

To ensure that there is no misunderstanding about the level of work required, both the intent and the scope of the work can be explicitly stated in each technical specification section.

A typical paragraph on the intent of the work might read:

Intent of Wood Window Restoration Work: It is the specific intent of this Section that at completion of the Work, all windows (including frames, sash, trim, glass and glazing, and hardware) indicated to be restored shall be completely restored to first class visual and operating condition. All wood frames, sash, and trim shall be restored to sound condition and original profiles. All hardware shall be restored to as new condition.

The scope of work on a comprehensive restoration project might include disassembly (removal of interior stops, sash, hardware), glazing putty removal and glass removal, paint removal, removal of deteriorated wood, consolidation and patching, dutchman repair, member replacement, joint repair, treatment of dry wood, priming, glazing, painting, hardware restoration, hardware installation, weatherstripping, and reassembly. In projects in which the windows were in better condition to begin with, the list of work might be much shorter: the windows might not be disassembled or the coatings removed, and the tasks might be limited to glazing putty replacement, preparation and painting, and adjusting and repair of hardware.

If the windows are to be weatherstripped or otherwise thermally upgraded, requirements for maximum air infiltration, minimum R-value, or other performance factors can be included.

Obtaining Qualified Contractors and Craftspeople

No matter how detailed, specific, and restrictive the technical specifications, high quality window work on historic buildings can only be ensured when the work is performed and supervised by qualified craftspeople. Obviously, those actually performing the work must be knowledgeable and experienced with the tasks required. However, even skilled craftspeople working under a general contractor who understands only the bottom lines of time and money and not the special requirements of restoration may have trouble producing high quality work.

On private projects, quality may be ensured by negotiating with one qualified contractor or
bidding the work to several preselected qualified contractors. On public projects—those on federal, state, or local government buildings and those involving federal or state funds—the specification sections and bidding documents should strive to ensure that both the general contractor and the subcontractor for window work are qualified to perform the level of work required.

Requirements for the craftspeople needing specialized skills and experience to perform the work can be inserted in the relevant technical section. Qualifications will vary depending on the project. Typical language for high-quality window restoration work on a significant historic building could require that the work be performed by a Restoration Specialist with a minimum of five years experience in comparable wood window restoration work on significant historic buildings, including successful completion of work on a minimum number of significant historic buildings under the direction of federal and state historic preservation agencies.

The bidding documents should contain forms that provide the architect with information for evaluating the contractor, the subcontractors, and the craftspeople who will perform the work. The information requested should include names of, information about, and references for contractor’s and subcontractor’s previous projects that have included similar work on historic buildings and the names and previous experience of craftspeople who will be employed in technical and supervisory positions.

Although it is widely believed that requiring specific qualifications on public work is not allowed by public bidding laws, over the past decade court decisions in the State of New York have upheld special qualifications for restoration work. One judge stated that if requirements for previous work on significant historic buildings had not been included in the bidding documents the government body “may well have acted in violation of their duty to find an experienced, qualified and responsible general contractor for this complex task.” An office of the General Services Administration has also developed a comprehensive set of requirements to be met by contractors and subcontractors bidding on restoration work on federal buildings under their jurisdiction.

General Project Conditions

General requirements should include considerations for protection, coordination, environmental conditions, and safety. In projects where window restoration work requires removal of sash and in projects where replacement wood windows are to be installed, the requirements should ensure that the interior of the building is protected both from weather and from unauthorized entry.

Requirements for coordination should provide for proper coordination of the work of all sections that specify window restoration work to provide the best possible result. For example, where window restoration work is performed on site, the consolidation and patching of deteriorated wood members should occur as soon as possible after paint has been removed and the painting of the members as soon as possible after the consolidation and patching. Where the required work is specified in other sections, the sections containing the requirements should be clearly referenced.

Requirements for environmental conditions should provide for proper temperature and humidity during work—such as consolidation and patching with epoxy resins, installation of dutchmen or replacement members, glazing, and painting—that requires special conditions for proper performance. The highest quality work can usually be obtained by somewhat narrowing the limits of temperature and humidity contained in master specification sections or manufacturer’s recommendations so that materials are not expected to perform near the outer limits of their capabilities.

Safety requirements should ensure—without specifying the contractor’s means and methods—that everyone involved with the work takes all precautions necessary to keep both workers and the public from harm caused by the work, to keep other elements and surfaces of the building and site free from damage or deterioration, and to prevent contamination of the environment. Of particular concern are the vapors generated by the use of epoxy resins and all aspects of work with existing paint or glazing compound containing
lead. The specification should also require the proper, legal handling and disposal of lead-containing materials.

Submittals and Quality Control Panels

Submittals and quality control panels are means used before general window restoration work or new wood window work is begun to ensure the quality of the finished work.

Special submittal requirements, including schedules, samples, and test panels, can be used to ensure quality. For complex restoration work where (for lack of access or other reasons) a comprehensive window survey was not made prior to writing the specifications, a window restoration schedule can be required. Prepared by the craftspeople after a thorough examination of each window, this schedule, listing all of the work to be performed on each unit, can provide a check on the scope of the restoration work.

Samples of each product used for the work should be required. Samples for window restoration can include each type of wood to be used for repair or replacement, each molding profile with samples of the original profiles to be matched, consolidation and patching materials, replacement glass, and replacement hardware. Samples for new replacement windows can include hardware and a full-size sample of each type of window required.

Test panels can include trials of different methods of paint removal, glazing compound removal, and other work for which the most appropriate method to be used may not be apparent before the specifications are written. Requirements for test panels should detail the options available, the procedures to be followed for each test, and the methods to be used in evaluating the results. It is always preferable, when the project allows, to test methods before the specifications are written. The fewer the unknowns at the time of bidding, the more reasonable the bids are likely to be.

Quality control panels (usually inserted in the Quality Control paragraph) are units of work that are to be completed by the craftspeople and approved by the architect before the general window restoration work is begun. Such items may include areas of wood consolidation, dutchman repair, member replacement, and one completely restored window of each type. If the panels are not acceptable, they should be remade until they are approved. Approved panels provide the minimal acceptable standards for accepting the window restoration work.

In some cases, it may be possible to have selected craftspeople restore one window of each type during the preparation of contract documents to serve as a standard. The work on these windows can help the specification writer clarify the tasks required and the general quantity of the work. In addition, these windows demonstrate the level of workmanship required to contractors during the bidding process.

Products

Requirements for many of the products used in window restoration and replacement wood windows can be borrowed from master specification sections. Some of the products used for window work on historic buildings, however, may have specific requirements.

Wood for dutchman repairs, member replacement, and replacement sash should match the wood of the original elements in specie, grade, and cut. If the window is to have a transparent finish, the wood should match in grain pattern as well. In some cases, where the original wood came from old-growth trees, reclaimed wood may provide the most appropriate match. The moisture level of the wood to be used for repairs should be nearly the same as that of the existing wood.

Consolidation and patching materials should be specifically designed for wood repair and should have physical properties compatible with those of the wood on which they are used. The materials should be flexible enough to avoid either cohesion failure or, more likely, cracks in the wood caused by forces exerted as the wood expands and contracts. The consolidant should have a viscosity low enough to allow full penetration of deteriorated wood.

Replacement glass should match existing glass. Usually cracked existing glass is replaced; sometimes in buildings of great historical significance, the cracks are glued using appropriate resins.
Several sources of restoration glass provide glazing appropriate to different historical periods. In some cases, salvaged glass can be used.

Replacement hardware should be specified to match existing hardware. Where there are a few damaged or missing pieces of hardware on a small-scale project, it is often possible to find matching replacement hardware salvaged from other buildings. There are also many more sources producing copies of historic hardware now than there were even ten years ago. Depending on the significance of the building and its windows and on the scale of the project, the hardware can be specially made to match the original.

Other elements of historic windows may have special requirements. Sash cord is one example. On two significant historic structures, the sash cord was specified to be hand twisted of individual fibers to match the original cord in material, number of fibers, and construction.

**Restoration Procedures**

The overall procedure for restoring the wood windows and the individual procedures for accomplishing each task required for the restoration should be outlined.

The general procedure for the work on each window includes the order in which the work is to be accomplished. For example, removal of stops, removal of sash, removal of glazing putty and glass, etc. Each of the window elements should be labeled so that it can be replaced in its original location. Glass panes, for example, may be of slightly different sizes; each pane should be replaced in its original position. The hardware from each window can be placed in small cloth bags labelled with the window number.

Individual procedures should be described in detail when the way they are performed will have an effect on the quality of the work. Sometimes, there are many ways of accomplishing a task. If one method is preferred, it should be specified. If one or more of the methods is unacceptable, they should be prohibited. The selection of equally acceptable procedures can be left to the craftsman. In the case of glazing putty removal, for example, the work can be done using a heat plate, a heat gun, a torch, a chemical softening agent, or a number of mechanical tools. Open flames should always be prohibited because of the danger of fire. Heat guns may cause the glass to break from stresses formed by uneven heating. Some mechanical tools are so aggressive that they can damage the wood members. Heat plates and chemical strippers may be successfully used to soften the glazing putty so that it can be removed using a putty knife. Safety considerations may also affect the selection of acceptable methods. In removing glazing putty from historic windows, it is possible that lead may be a consideration.

The way in which the repair of the wood members is specified depends on the level of the window survey and the size of the project. Ideally, the type of repair required on each wood member should be shown on drawings or listed in the window schedule. If the exact level of repair for each member has not been determined before the specifications are written, the work can be specified by objective criteria. Although the criteria can vary greatly depending on the project, a typical specification might include the following:

- Provide epoxy consolidation and patching for sections of deteriorated wood with a volume of less than 4 cubic inches to provide sound wood members to original surface planes and profiles.

- Provide dutchman repair to replace sections of deteriorated wood with a volume of more than 4 cubic inches but extending less than one-third the length of the member to provide sound wood members to original surface planes and profiles.

- Replace severely deteriorated members and members with less severe deterioration when deterioration occurs at joints.

Projects on the most significant historic structures might permit less replacement; those on less significant structures might permit more.

In the restoration of early windows, wood for dutchman repairs, member replacement, or replacement sash must be hand-planed to provide a surface matching that of the original. Even under several coats of paint, marks from modern rotary planer blades and molding cutters are incongruous in eighteenth century wood members. In these cases, the specifications can allow the members to be roughed out at least 1/8 inch.
oversized with power tools and worked to their final profiles with hand-powered planes. Where profiles of replacement members are required to match original profiles, the paint must be removed completely from the original members before the profiles are taken.

The specifications should provide detailed instructions for the use of consolidants and patching materials, including the removal of deteriorated wood, preparation of the remaining portions of the wood elements for consolidation, application of the consolidant, application of the patching compound, and finishing to final surfaces and profiles. Manufacturer’s directions should be followed. With the use of many epoxy resins, a full bond cannot be developed between the consolidant and patching compound unless the patching compound is installed before the consolidant has completely cured.

Experience has shown that when installing dutchmen, the perfectly fit dutchman with a hairline glue joint may not perform as well over time as a dutchman that is cut slightly short with a wider flexible glue line. Slight expansion and contraction can be taken up in the joint before sufficient force is generated to disturb the finish. On installation, the visible surface of the dutchman should be slightly proud of the surrounding surface. After the glue has set, the surface can be planed to match the level of the adjacent wood.

Replacement sections of members should be installed using lap joints or tongue-and-groove joints. It is usually easier to provide details of typical conditions on drawings than it is to describe them in the specifications.

Loose joints in sash members should be tightened using wedges and/or pegs following the methods used in the original construction.

The level of hardware restoration should be specified. It can range from simple cleaning to replacing missing or deteriorated elements and completely removing the finish and refinishing. In some cases, historic finishes may need to be recreated. To reproduce the finish used on steel hardware in a building from the 1890’s, for example, it was necessary to find a catalog from the original manufacture, which named the type of finish, and then to find the patent for that finish, which described how it was created.

Wood Replacement Windows

Although many of the requirements for window restoration are also applicable to replacement windows, the latter often have additional requirements, which may include preservative treatment and limits on air infiltration. Most of these requirements are the same as, or can be modified from, the standards in new wood window sections of master specifications.

Quality versus Cost

As with all other aspects of construction, the tighter the specification and the more requirements included to ensure quality the higher the cost of the work is likely to be. Such items as a contractor’s window restoration schedule outlining each unit of work to be accomplished and quality control panels of each type of work required add to the cost. It is necessary to balance the quality of the work required with the cost of the work based on many factors, including the significance of the historic building and its materials.