CHAPTER 4
ENERGY AND CODES

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THE ROLE OF WINDOWS IN OVERALL BUILDING PERFORMANCE: THE ENGINEER'S STORY

William B. Rose
Research Architect
Building Research Council, University of Illinois
Champaign, Illinois

Executive Summary

The role of the mechanical engineer (ME) is to provide an indoor environment suited to comfort and use. Historically, mechanical engineers have been very concerned with the building envelope because it wraps the environment they try to create. The envelope (walls, windows, roofs) provides input values for mechanical design, and it may be the first indicator of things going awry. Windows, in particular, concern the ME because they play a large role in heat loss, cooling load and infiltration, and also because of the annoyance of window condensation.

The purpose of this paper is to present the case of the ME who is faced with an old building having old windows. Engineers use heat loss and cooling load models that require best-guess input parameters; often engineers will recommend a window changeout simply to have the benefit of specified rather than indefinite transmission and leakage characteristics. The first aim of this paper is to run the models an ME would typically use and to determine how sensitive the system design might be to a range of window transmission and leakage values. We will find that, in most cases, the system design or performance is not strongly affected by the window choices; where the design or performance is affected, the effect is quantifiable.

The second aim of this paper is to discuss window condensation in light of an ME's concerns. The paper will address: the kinds of window condensation, the conditions under which it occurs, the options for preventing it, and the consequences for allowing it. It will focus on the efforts an ME usually will take to prevent window condensation, and it will discuss the consequences of those efforts for the building.

In summary, the paper will assist building professionals who must assess the requirements an ME might impose on window design, compared to the requirements that other interests would impose such as quality of light, conformance with preservation standards, cost, and aesthetics.

Introduction

This article is written to help preservationists in their dealings with mechanical engineers (ME) regarding window issues. Some preservationists complain of being design-mugged by overbearing mechanical engineers who hold the indoor environment hostage unless the building owners, managers or designers pay a hefty ransom in duct space, replacement windows and gutted wall assemblies. Other preservationists have grown to appreciate the skill of mechanical engineers, whose work can contribute vitally, and with sensitivity, to the preservation of buildings and the conservation of artifacts. There is a widespread sense that mechanical engineers are from Mars and preservationists are from Venus. It is not true. There is much in common, as this paper hopes to demonstrate.

The aim of this paper is to provide some guidance for preservationists who would opt against window replacement (following the Secretary of
the Interior’s Standards), but who are faced with recommendations from a mechanical engineer that tend toward replacement rather than reuse. It aims to assist the preservationist to assess the requirements a mechanical engineer might impose on window design, in light of the other requirements for windows including quality of light, conformance with preservation standards, cost and aesthetics.

Overview of Mechanical Engineering for Historic Buildings

In the U.S., the largest professional association of mechanical engineers is the American Society of Heating, Refrigeration and Air Conditioning Engineers (ASHRAE), which, prior to the 1950s, was the American Society of Heating and Ventilating Engineers (ASH&VE). ASHRAE publishes and maintains four handbooks (Fundamentals, Systems, Applications, and Equipment), a journal, transactions, and several standards. Within ASHRAE, there is no committee which addresses the concerns of historic buildings per se. Historic buildings are taken to be like other buildings, although older and with fewer of the envelope niceties that an ME expects to be incorporated into the walls, windows, and roofs at the time of new construction. Preservationists will most likely use an ME firm with an established general reputation, though they may seek the services of consultants specializing in the field of mechanical equipment in historic buildings.

Since windows enclose the indoor environment, they have been a matter of concern for mechanical engineers from the outset of the profession. Principal concern for an ME is the effect of windows on load calculations. Load calculations are the estimates of heat and moisture exchange between the indoors and outdoors, and they serve as the basis for sizing decisions, system design and eventual energy use.

The first coefficients of heat transfer through building materials, including glass, were determined by Sir William Thomson in Great Britain and Peclet in France, and were reported to ASH&VE in 1897. Through the early part of the twentieth century, the concern was the thermal conductivity of glass during the heating season and its contribution to heat losses. (Cooling loads were rarely an issue.) Insulated glass was imagined but the airtightness of the seal was a commercial impossibility until after WWII.

Over time, the mechanical engineering profession has sought to standardize the process of estimating heating and cooling loads. The process was first standardized in 1979 in the ASHRAE Cooling and Heating Load Calculation Manual GRP 158 for buildings in general, and in ACCA/ARI Manual J for residential buildings in 1981. These methods are “steady-state” as opposed to “transient.” Steady-state analyses use single values of extreme conditions as inputs. Transient models use weather data on an hourly or daily basis to calculate loads. The most commonly used transient models are those based on BLAST (developed by the U.S. Army Corps of Engineers) or DOE2 (developed by the U.S. Department of Energy). Almost all engineers, even those in small and mid-size firms, now use transient analysis models to calculate loads. They typically use software (usually based on BLAST or DOE2) provided by the larger HVAC equipment manufacturers. The system designer has the odious task of entering all of the building envelope components by area, orientation, heat transmission, light transmission, etc. A weather tape is provided to model a climate similar to the climate at the site. The program provides a load calculation output table like that shown in the table of Figure 1. The discussion between the preservationist (owner, manager, architect, designer, contractor, etc.) and the mechanical engineer will usually take place with the load calculation table as the centerpiece of that discussion.

The two ways in which windows (assumed closed) increase the heating load of a building are through thermal conductivity and infiltration. Windows affect the cooling load with the additional contribution of light transmission. The indoor environment affects windows by allowing or preventing window condensation. The remainder of this paper will present:
Figure 1. Sample peak load calculation output from a standard load calculation program that a mechanical engineer might use (TRACE 600, from Trane), available from equipment manufacturers. Note 1) the relatively small contributions from window conductivity for summer and winter, as a percentage of total, and 2) zero infiltration. Infiltration is subsumed into ventilation, shown here as Outside Air.
- Infiltration and Ventilation
- Conduction and Light Transmission
- Window Condensation

In ways that go beyond load calculations and system design, mechanical engineers are concerned with assuring human comfort. In contrast, some preservationists may accept a degree of discomfort as a fact of life in old buildings. Thermal comfort for users depends on:

- maintaining temperature within a range consistent with clothing and activity
- avoiding drafts in wintertime and enhancing air movement in summer
- avoiding radiant hot spots and cold spots.

Windows play a significant role for each of these factors, although a detailed discussion on this topic is beyond the scope of this paper.

**Infiltration and Ventilation**

Historically, the wild card in all load estimates has been the load contribution through infiltration, the replacement of indoor air with outdoor air through unintentional cracks and openings. The common unit for expressing overall air exchange is air changes per hour (ach). Figure 2 shows two histograms of infiltration rates in new buildings and in low-income housing. Mechanical engineers would typically expect infiltration rates like those shown for new construction; preservationists are familiar with buildings that have infiltration ranges and distributions like those shown in the lower chart.

Not all infiltration is through windows. *ASHRAE Fundamentals* includes the table below, which provides a rough estimate of the relative contribution of the various parts of the building assembly.

From this table, after subtracting an estimated value for door contribution, one can arrive at a rough estimate of the infiltration contribution by windows from the window/door total, of only five percent to 20 percent of the total infiltration. Consequently, upgrading from leaky windows to tight windows does not make an overwhelming difference in the total infiltration rate of the building.

Another, rather outdated, method of estimating leakage area due to windows uses the "crack method," where, based on testing and experience, an effective leakage area is assigned to windows as a function of the perimeter length of the window. *ASHRAE Fundamentals* allows these effective leakage values, as well as factors for wind, building height, fans, etc., to be used to estimate air exchange rates. The table of values from ASHRAE is presented below, not to calculate infiltration rates, but to give a sense of the relative leakiness of various window assem-

<table>
<thead>
<tr>
<th>Component</th>
<th>Range of Infiltration Contribution</th>
<th>Mean Infiltration Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Walls</td>
<td>18 to 50%</td>
<td>35%</td>
</tr>
<tr>
<td>Ceiling details</td>
<td>3 to 30%</td>
<td>18%</td>
</tr>
<tr>
<td>Heating System</td>
<td>3 to 28%</td>
<td>18%</td>
</tr>
<tr>
<td>Windows and doors</td>
<td>6 to 22%</td>
<td>15%</td>
</tr>
<tr>
<td>Fireplaces</td>
<td>0 to 30%</td>
<td>12%</td>
</tr>
<tr>
<td>Vents in conditioned spaces</td>
<td>2 to 12%</td>
<td>5%</td>
</tr>
</tbody>
</table>

*Table 1. Percent contribution to total infiltration by component.* *(From 1993 ASHRAE Fundamentals.)*

<table>
<thead>
<tr>
<th>window type</th>
<th>best est.</th>
<th>minimum</th>
<th>maximum</th>
</tr>
</thead>
<tbody>
<tr>
<td>Double hung, no weatherstripping</td>
<td>1.3</td>
<td>0.44</td>
<td>3.1</td>
</tr>
<tr>
<td>Double hung, with weatherstripping</td>
<td>0.33</td>
<td>0.1</td>
<td>0.97</td>
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<tr>
<td>Double hung, with storm</td>
<td>0.5</td>
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<td>0.86</td>
</tr>
<tr>
<td>Double hung, weatherstripping and storm</td>
<td>0.4</td>
<td>0.22</td>
<td>0.5</td>
</tr>
<tr>
<td>Inside storm, magnetic seal, rigid panel</td>
<td>0.061</td>
<td>0.009</td>
<td>0.12</td>
</tr>
</tbody>
</table>

*Table 2. Effective leakage area, square inches per lineal foot of crack.* *(From 1993 ASHRAE Fundamentals.)*
Mechanical engineers may be accustomed to air exchange rates typical in new construction, but the distribution of air exchange rates for historic buildings may more closely resemble the exchange rates for low income housing. (From ASHRAE 1993 Fundamentals.)

A wealth of information on infiltration and ventilation of buildings is available through the Air Infiltration and Ventilation Centre (U.K.), established by the International Energy Agency. The infiltration variable is rarely quantified. Mechanical engineer colleagues tell me that they may design a system by intuition and experience, then, in the supporting documentation, "dial in" the infiltration value that most closely supports their design and that excludes alternate designs. This may not reflect the best practice, but it does reflect the indeterminacy of air exchange rate estimates in the variety of existing buildings.

Infiltration can be defined as accidental air leakage and ventilation as intentional air leakage. One of the most significant (and controversial) changes in ME practice is the introduction and widespread use of ASHRAE Standard 62. This standard calls for fresh air ventilation to be provided to many public buildings by the mechanical system, not accidentally through infiltration. It calls for 15, or in some cases 20 or more, cubic feet per minute (cfm) of fresh outdoor air to be supplied to each occupant (using a "design occupancy"). The net effect of the application of ASHRAE Standard 62 is that many buildings assigned to this standard, at least those that are moderately airtight, will have no infiltration. That is, all of the air exchange across the building envelope will be intentional rather than accidental. Mechanical engineers may commonly assign a value of zero to the infiltration load in ventilated buildings. See Figure 1.

Should ventilated historic buildings have an assigned infiltration value of zero? Perhaps, but not necessarily. There are three remaining infiltration concerns, which could occur: 1) after the ventilation need has been satisfied, 2) after hours, when the fresh air requirements are not in effect, and 3) locally, making one area or zone of the building difficult to satisfy or balance. The first and third should not be a great concern if the historic building has been moderately weathered at the time of the HVAC installation. The second may have an impact on the overall energy consumption, but should not affect sizing of equipment.

The preservationist may wish to do a quick calculation of the building air change rate with mechanical ventilation. The air change rate with mechanical ventilation will be the design occupancy (number of persons) times the fresh air requirement (often 15 cubic feet per minute). An infiltration rate will be the estimated number of air changes per hour (say between 1 and 0.5) times the building air volume. These numbers may be quite close to one another.

While ASHRAE 62 applies to most public buildings, residences are one example of a building type that may have no requirement for mechanical provision of fresh air. An hydronic heating system may still be specified and designed where infiltration is the default method for provision of fresh air. Local codes and their interpretation will determine if ASHRAE 62 applies.
It is important to point out that most of the time, the total air change rate for a mechanically ventilated building will be dictated simply by mechanical settings. Historic buildings are commonly provided with fresh air intakes, but with no provision for exhaust other than through cracks. Such buildings are termed "pressurized." This is desirable in any building that seeks to control the quality of the indoor air. However, it could be dangerous during very cold weather in humidified buildings that have insulated cavities. Positive pressure is beneficial for air quality, for rain performance of the building assembly, and for summertime performance of building cavities. Reductions in the "positiveness" of the indoor air pressure is desirable only in humidified buildings during the coldest weather. Positive air pressure may increase the likelihood of window condensation with storm windows. See the discussion below.

In short, one of the most common arguments for window replacement – reducing infiltration – is not very compelling, especially in buildings with designed ventilation and moderate measures taken to ensure air- and weather-tightness.

Heat Conduction and Light Transmission

The difference in heat conduction for different window units is quite straightforward and allows for easy comparison of the performance of different window designs and strategies.

The overall coefficient of heat transfer of any glazed opening is called its U-factor. This value represents the combined area-weighted thermal conductivities of the different window components (pane, sash, and frame). The rated U-factor also includes a value for the thermal resistance of the air films that are on the inside and outside, and that are between the panes. The air films can be very important especially on single-glazed windows: with only a slight wind outdoors the indoor air film may contribute half of the total thermal resistance of the window; and with a normal wind outdoors, the indoor air film may contribute two-thirds of the total thermal resistance (see “Window Condensation,” below).

The National Fenestration Rating Council (NFRC) was established in 1989 to develop a fair, accurate and credible rating system for fenestration products. Most residential size window units now carry an NFRC label. RESFEN, a residential fenestration software application available from NFRC, uses NFRC ratings to determine energy use in buildings, is available from NFRC, and can be downloaded through the Internet. Figure 3 lists various window products and typical ratings that affect their energy performance. The total window U-factor of single glazing is twice as great as the U-factor for clear double-glazed insulated glass, and several times greater than the U-factor for more technologically advanced windows. The heat loss is directly proportional to the U-factor and the window area. From this, the load implications of the fenestration choice is quite straightforward. But what part of the total load is made up by the thermal conductivity (U-factor) glazing choice?

One early snapshot of mechanical engineering design for winter heating written at the threshold of the introduction of insulation is the 1946 Heating Ventilating and Air Conditioning Guide, the predecessor of the current ASHRAE Fundamentals. In the 1946 example heat loss problem (a residence), much of the heat loss was through the doors and windows. By their calculations, with single-pane glazing:

- with uninsulated walls, 21 percent of the heat loss was transmission loss through glass and doors, and 13 percent of the loss was through infiltration
- with insulated walls, the transmission loss through glass and doors was 33 percent and the infiltration loss was 20 percent
- no credit was given for sunlight entering through the windows.

It is clear from this example that the percent contribution to heat loss from the window depends on the energy efficiency of the opaque parts of the building envelope.

In the same 1946 guidebook, the summer example is given of a clothing store with air conditioning, a flat roof, south and west glazing, and a 50-person design occupancy. In this case, 15 percent of the total cooling load compensated for the thermal transmission through the win-
<table>
<thead>
<tr>
<th>Characteristic</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>Characteristic</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>11</th>
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<tbody>
<tr>
<td>Layers of glazing and spaces (outside to inside)</td>
<td>1/8&quot; clear</td>
<td>1/8&quot; bronze</td>
<td>1/8&quot; clear</td>
<td>1/8&quot; clear</td>
<td>1/8&quot; bronze</td>
<td>1/8&quot; clear</td>
<td>Layers of glazing and spaces (outside to inside)</td>
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<td>1/8&quot; low-E (0.08)</td>
<td>1/8&quot; low-E</td>
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<td>U-factor</td>
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<td>0.76</td>
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<td>Frame Type</td>
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<td>Aluminum</td>
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<td>0.49</td>
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<td>0.65</td>
<td>0.37</td>
<td>0.37</td>
<td>0.37</td>
<td>Air leakage</td>
<td>cfm/ft²</td>
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<td>0.10</td>
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<td>0.10</td>
<td>0.05</td>
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<tr>
<td>cfm/sq ft</td>
<td>0.98</td>
<td>0.98</td>
<td>0.56</td>
<td>0.56</td>
<td>0.56</td>
<td>cfm/sq ft</td>
<td>0.15</td>
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<td>0.15</td>
<td>0.15</td>
<td>0.06</td>
<td>0.15</td>
<td></td>
</tr>
</tbody>
</table>

Units for all U-factors are Btu/hr·ft²·°F. All values for total window are based on a 2 foot by 4 foot casement window.

dow s, and 9 percent compensated for the sunlight that came through the windows. Infiltration was considered a beneficial contribution to the occupant need for fresh air, and there was no penalty attributed for infiltration; instead, 25 percent of the cooling load was to meet the occupants' needs for fresh air. It is clear from this example that in ventilated buildings, fresh air ventilation provides the overwhelming load contribution, especially in summer.

A more up-to-date analysis is shown in Carmody et al., Residential Windows: a Guide to New Technologies and Energy Performance. Figure 4 shows the impact of improved glazing on annual energy performance for three climate areas, using a model building that is a well-insulated wood-framed ranch residence. The significant improvement lies in the use of double-rather than single-glazing. While average energy use is important, peak energy use may be more significant, since the selection of equipment size depends on the peak values. Equipment sizing affects not only the capital cost for equipment, but also the volume required for equipment and ductwork. Figure 4 shows peak values for the residential example.

It is clear that the greatest contribution to energy efficient performance comes from adopting a double-glazed rather than a single-glazed system.

Regarding heat gain from solar transmission through windows, the energy incentives and the preservation incentives mesh very well. The summertime cooling performance of a building is enhanced by any measure that reduces light energy transmitted to the indoors. Such measures include shades, films, tinting, drapes, etc. The conservation of interior finishes and artifacts is enhanced by the adoption of these same measures.

Window Condensation

In the early part of the century, buildings were rarely humidified. Notable exceptions were printing plants (that needed dimensionally stable paper), textile mills (that needed to reduce lint concentrations in the air) and wet processes such as laundries. Window condensation was only considered a problem in such buildings, as well as in schools, which had high occupant loads and large glazing areas. It was rarely viewed as a
problem in residences. A 1929 commentary on window condensation noted:

Moisture on windows either in the form of condensation or frost causes no great annoyance in the majority of instances. However, in some cases, this formation on the windows is not only annoying but very detrimental... There are several reasons why the problem has grown more acute. The advantages of higher humidity of the air have resulted in the development and use of means for maintaining a higher moisture content than formerly. Better construction, at the window openings, has materially reduced the rate of exchange between the inside and outside of buildings, thus causing a building up of the moisture content of the inside air. Buildings nowadays have a much greater window area, and the amount of condensation is dependent upon the amount of window surface.\(^\text{11}\)

Willis Carrier, the father of air conditioning, commented, following the presentation of a paper\(^\text{12}\) giving the conditions of indoor air that led to window condensation, “For my part, I like to see a little condensation to know you have a little moisture there. That is the practical limit... Right now I have two humidifiers delivering altogether about half a gallon for water an hour into the house, and that just barely keeps the humidity enough, and I can see just a trace of condensation on a cold day.”

Window condensation is a consequence of indoor moisture generation during cold weather. There are various forms of window condensation, some more benign than others. Condensation that runs or streams down windows, puddling at the sill or damaging the paint finishes of the historic sash, frame, or trim, deserves to be eliminated. Such condensation usually indicates high indoor humidity, especially when it occurs on insulated glass, condensation may indicate that moisture damage is occurring in other building cavities that are loaded with indoor humidity. Condensation that forms a film of dew or frost, or simply evaporates from the pane, has no deleterious effect on the window.

The likelihood of condensation depends on the temperature of the interior surface of the pane and the dew point temperature of the air that faces that pane. The condensation potential depends entirely on the type of window, whether

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single pane, interior storm, exterior storm or insulated glass (IG). Figure 5 shows the allowable indoor relative humidity for a given outdoor temperature, for different glazing types.

Windows with single glazing will have an interior surface temperature that is closer to the outdoor temperature than to the room temperature. Thus they are likely to show condensation during cold winters if there is any appreciable humidification in the building. Only in the southern U.S. could single pane windows remain free from condensation during the winter months.

Condensation can form on the inside surface of outdoor storm windows. This is very common in the beginning of winter. Even streaming condensation may not be damaging when it occurs here, because it runs to the sill which should withstand water loading. This condensation occurs in pressurized buildings, or in parts of buildings with positive pressure. One common example is condensation on the windows at the upper floors of a two- or three-story building, with buoyancy as the driving force for pressurization at the top.

During very cold weather, condensation is problematic in window units composed of a single-pane prime window and a single-pane storm window. The usual site for condensation is on the inside surface of the outer pane. Alleviating this problem requires that the cavity between the two windows be filled with outdoor air, and that indoor air be excluded from the cavity. This would require very effective sealing of the inner window and its jamb, head and sill, and considerable ventilation of the outer window. Two weep holes at the bottom or the window would not suffice. Additionally, if outdoor air continually flushes the cavity between the panes, then it may cause the inner window to be cooled down to the point of condensation. Given the difficulty of achieving such a seal, it is usually advisable to use insulated glass or plastic as a storm. If the storm is located outside, the historic sash will be better protected but the exterior appearance will be affected. If the storm is located at the interior, the outside building appearance is enhanced but there is a negative impact on security and weather protection of the original window, and condensation may persist.

Certain window treatments will contribute to the likelihood of condensation. Drapes and light screens placed on the inside of windows will capture an air space, which will act as an insulator and further depress the window surface temperature. Bay windows, or windows pushed outward from the plane of the wall, are more likely to be sites of condensation because the outward protrusion will reduce the effectiveness of the outdoor air film, and the captured air space at the interior will act as a more effective insulator.

Radiators have historically been placed beneath windows in buildings with hydronic heating systems. The ostensible reason for this is to prevent window condensation by heating the pane surface and countering the downdrafts that would otherwise occur at the window in cold weather. But the placement of radiators beneath windows may have served two other purposes as well.

1) The cracks at windows are the sites of a considerable amount of air leakage. By over-heating the crack openings, there is a lessened likelihood of damage from exfiltrating humidified air.

2) The wall areas beneath windows are often the sites of water accumulation and water damage. This is because the mechanics of water discharge from the sill area is less than perfect. The overheating provided by a radiator may mitigate much of the potential damage.

There is not sufficient information at this time to determine if the wall areas under windows will begin to show increased damage with the abandonment and removal of radiators from beneath windows. However, this author would recommend that preservationists keep an eye out for moisture effects in walls where radiators have been removed.

In summary, window condensation is usually viewed as undesirable, and the ME may be at least partially responsible should it occur. Most MEs will review a window selection to help avoid condensation. In turn, the preservationist should:
- review the window specification with the ME for condensation potential
- review the indoor humidity and temperature settings
- distinguish benign and allowable condensation from that which can damage the building fabric
- know beforehand the courses of action should condensation become a problem

Corrective measures for window condensation include:

- reduction of the indoor humidity
- provision of a heat source near the condensing plane
- identification and correction of the factors that may contribute to condensation such as drapes or screens or storm windows

**Conclusions**

For a building with loose, unweatherstripped windows, a mechanical engineer would typically assume an infiltration load: this would require larger equipment and a greater use of energy than in a building assumed to have tight windows. In most public buildings with mechanical ventilation and moderately tight windows, mechanical engineers may assume a zero infiltration load for the building. The tightness difference between a weatherstripped or well-designed original window and a tight replacement window would then make no difference in the load calculations. For the preservationist, weatherstripping of windows to a moderate tightness nullifies the argument for installing tight replacement windows.

Adding a second layer of glazing to single-glazed windows may have measurable benefits in both equipment size and energy use, in particular in winter heating-dominated climates.

A reduction in light transmission is desirable in both historic and new buildings. Techniques for reducing UV and visible light that are familiar to preservationists include the installation of drapes, shades, films and special glazing. These installations are beneficial to interior finishes and to energy performance, thus rendering the preservation aims and the mechanical aims complementary.

Window condensation can be light or severe; severe window condensation should be avoided or prevented. Single pane windows are prone to condensation (and the resulting damage to finishes) if there is humidification from either natural or mechanical sources. Storm window assemblies may suffer condensation unless very carefully detailed. Window assemblies using insulated glass units are generally free from condensation. The mechanical system can control window condensation by allowing the indoor conditions to drift or be controlled to lower humidity as the outdoor temperature becomes colder, provided that this approach is acceptable to those responsible for the contents and artifacts inside the building.

Providing a heat source beneath windows remains an effective way to prevent most window condensation. Radiative and convective heat sources may not perform equivalently for the purposes of correcting moisture effects around windows.

Most historic buildings are maintained in positive pressure to allow filtration of incoming air. While in theory building depressurization could relieve the possibility of storm window condensation, in practice the results may be disappointing.

In summary, there are no compelling arguments from the field of mechanical engineering for replacing historic windows, provided the windows are moderately airtight, treated to prevent excessive UV and visible light transmission, and not prone to excessive condensation.
Notes

1 Carpenter, R.C., Methods of Proportioning Direct Radiation III, no. XXV (1897): 73.


5 Manual J includes a section on using “bin” data, which is an intermediate step between steady state and transient analysis, using several averaged periods.

6 Air Infiltration and Ventilation Centre, University of Warwick Science Park, Coventry CV4 7EZ, Great Britain. Internet: www.aivc.org.


8 National Fenestration Rating Council, 1300 Spring Street, Suite 120, Silver Spring, Maryland 20910. RESFEN download: http://eande.lbl.gov/BTP/BTP.html.


12 Ibid.
Executive Summary

The goal of retaining historic windows during building rehabilitation is often challenged by those who would prefer to replace them with modern windows. Concern for long-term energy conservation is one of the many important factors encouraging replacement rather than rehabilitation of wood windows. Few test data exist, however, that quantify the actual energy performance of existing and rehabilitated historic wood windows.

This study has performed over 150 in-place and several laboratory air leakage rate tests of pre- and post-rehabilitation historic wood windows. In these tests, heating season natural air infiltration and non-infiltration heat losses were modeled. These energy losses were subsequently summed and translated into annual heating season energy costs in order to estimate savings and to compare savings to costs.

Major results of this study include the following:

- Both retention and replacement strategies can result in high levels of energy performance, depending on the specific option selected and the quality of its execution.
- Decisions about window upgrade methods should be based primarily on decisions other than energy. However, once a general rehabilitation strategy is chosen, energy performance should be optimized, based on cost-effectiveness criteria appropriate to the project.

- The cost-effectiveness of upgrading the energy efficiency of windows is highly dependent on the performance of the existing windows. Little improvement can be expected from upgrading windows that already have low air leakage rates and that include a second layer of glass.

- Diagnostic whole-building air leakage testing should be used as part of a total building energy analysis to prioritize window air leakage treatment appropriately.

- Window heat loss accounts for approximately 20 percent of the total heat load for the typical building studied. Efforts to upgrade energy efficiency of windows should be placed in that context.

The project was funded by a grant from the National Park Service through the National Center for Preservation Technology and Training to the Vermont Division of Historic Preservation. The project team included the Vermont Energy Investment Corporation, the University of Vermont School of Civil and Environmental Engineering, and the U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire.
Introduction

When historic buildings are renovated, the question of how to treat the windows is inevitably raised. The desire to retain the historic character and the actual historic material of the windows is often seen as competing with the desire to improve energy performance. This discussion is multifaceted, including factors such as the historic character of the windows, ease of operation, maintenance costs, lead abatement, window longevity, occupant comfort and energy conservation. In northern climates, energy conservation can take a prominent role in the discussion, particularly in renovation of affordable housing, where long term energy costs can be more important than in other contexts.

To date, there has been little data that quantifies the impact on energy costs of either window renovation or replacement, or data that compares the estimated value of conserved energy to the installed cost for various retrofits or replacements. In 1995 the Vermont Division of Historic Preservation commissioned a study to investigate the energy performance of historic windows, before and after a variety of energy improvement retrofits. This study, funded by the National Center for Preservation Technology and Training, was designed to test the assumption that historic windows can be retained and upgraded to approach the thermal efficiency of replacement sash or window inserts.

Windows tested as part of the study were primarily in residential buildings in Vermont; most of these were in the process of renovation for affordable housing, a segment of the housing stock particularly concerned with long term energy costs. Tested windows were double-hung and generally of average quality when originally built. Approximately half of the windows were counter-weighted sash and half had either pin-type sash or no mechanism for holding one sash open. Their condition when tested varied widely, from very good to falling apart.

Quantifying Heat Losses Through Windows

This study concentrated on heating season energy loss through windows. Window heat loss can be divided into infiltration and non-infiltration losses.

Infiltration losses, driven by wind and by the temperature difference between the inside and outside of a building, occur primarily through cracks between the sash, the sash and the frame, and the frame and the rough opening. Non-infiltration losses include heat lost directly through the materials of the window.¹

Non-infiltration losses are difficult to measure in the field, but have been studied extensively in mobile test facilities and in controlled laboratory conditions. Much of this work was conducted by Lawrence Berkeley Laboratories (LBL) Window Division, which has developed a detailed computer model, Window 4.1, that is now widely accepted as highly reliable for determination of non-infiltration heat transfer through overall window assemblies. Window 4.1 was used in this study to model these losses, which vary little between windows with similar numbers of layers of clear glass and similar frame materials. In contrast, infiltration losses vary significantly from one window to the next. The American Society for Testing and Materials (ASTM) has developed a test to evaluate air leakage rates in the field, ASTM E783-91. This test results in an air leakage rate at a specific pressure across the window. In order to correlate such test data with an average heating season natural infiltration rate, a model of natural infiltration developed at LBL, the Sherman-Grimsrud model, was used.² The infiltration and non-infiltration heat loss rates were added together to obtain the total average heat loss rate.³

Data were normalized to a typical 36 inch wide by 60 inch high window size. A standard ASHRAE heat loss model was used to develop the first year heating load from the heat loss rate, and Burlington, Vermont, climate data and typical heating fuel cost and efficiencies were used to calculate the first year cost for heat for a window (Figure 1).

Infiltration Testing Method

The infiltration test method was modeled on ASTM E783-91. Two air leakage tests were performed on each window configuration. A plastic sheet was first taped onto the inside trim of the window, with an air hose and pressure tap attached (Figure 2). Air was drawn through the
window and the flow rate, in cubic feet per minute (CFM), was measured at various pressure differentials across the sheet. This test result was called “total leakage.” A second sheet was then attached to the exterior of the window and the test repeated. This test result was called “extraneous leakage.” The difference between these two values is called “sash leakage.” Sash leakage at a specified pressure is the value reported in window manufacturers’ literature for the air leakage rate (Figure 3).

Sash leakage is often understood by building designers to include all the air leakage due to the window. However, leakage between the sash and rough opening can make a significant contribution to overall air leakage. In order to estimate the contribution of rough opening leakage, temperature measurements were made of the indoor air, outdoor air, and the air being drawn through the window during the extraneous leakage test. On average, the temperature of the air drawn through the window was approximately 30 percent cooler than the indoor air, compared to the outside air, indicating that roughly 30 percent of the extraneous leakage was coming from outside. While this method is far from exact, it served to give a value
that could be used during analysis to 1) indicate that this leakage is recognized as contributing to the heating load, and 2) approximate the magnitude of the contribution to the heating load of air leakage through the rough opening. Total leakage from the exterior is then estimated as sash leakage plus 30 percent of extraneous leakage.

In addition to air leakage testing, physical measurements were made of the windows, including materials types, sizes and dimensions. Various visual parameters were recorded, in an attempt to correlate the results of a visual inspection with air leakage rate. Cost estimates for window upgrades were based on interviews with the housing developers and/or builders, and were normalized to a $20 per hour labor rate.

Windows tested

Windows tested were located primarily in affordable housing projects undergoing rehabilitation in Vermont. Test locations were limited by building access and condition of the windows and surrounding surfaces. Pre-treatment windows had to be sufficiently intact that the pressure exerted during the testing would not break glass, and the surrounding surfaces had to be large enough and smooth enough to allow application of masking tape. Sixty-four pre-treatment windows were tested, of which approximately half were windows with sash balances and half were windows with pin-type mechanisms or no mechanism for holding sash open. Eighty-seven post-treatment windows were tested: treatments included a wide variety of improvement strategies. Table 1 summarizes the general upgrade categories tested and the number (n) of each, with some windows falling into two categories. See Figure 4 for schematics of window upgrades tested.

Table 1: Number of windows tested by general upgrade category.

<table>
<thead>
<tr>
<th>General Window Upgrade Category</th>
<th>n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retained original sash</td>
<td>62</td>
</tr>
<tr>
<td>Replacement sash with vinyl jamb liners</td>
<td>11</td>
</tr>
<tr>
<td>Replacement window inserts</td>
<td>12</td>
</tr>
<tr>
<td>Whole window replacements</td>
<td>2</td>
</tr>
<tr>
<td>Replacement storm windows</td>
<td>17</td>
</tr>
<tr>
<td>Double- versus single-glazing replacements</td>
<td>19</td>
</tr>
</tbody>
</table>

Results

Results for original windows. Air leakage rates of original windows ranged widely, due to the large variation in condition of the windows. Inspection of the data indicated that there were no strong correlations between visual parameters and air leakage rates beyond a weak correlation between the fit of the sash at the meeting rail and air leakage, and a weaker correlation between fit of the sash to the frame and air leakage. Whole building air leakage testing, using a blower door and a smoke pencil to identify leakage locations, can be useful in identifying and locating air leakage paths. The spring-loaded interior storm sash, site 10A, had a remarkably low sash leakage rate of 0.05 scfm/lfc (at 0.30 inches water pressure) and the magnetic strip/plexiglass interior storms at site 15 had a sash leakage rate of 0.01 scfm/lfc.

All windows with operable storms were tested with storms both open and closed. A mean air leakage rate was established for all original (pre-treatment) windows that had operable storms in place, called the “Typical” window. The “Tight” window was assumed to have one standard deviation lower leakage rate. The “Loose” window was the average of all original condition (pre-treatment) windows with storms open or missing. This established three baseline windows for comparison with rehabilitated windows, in order to 1) emphasize the variability in air leakage rates of existing windows, and to 2) emphasize that energy performance comparisons for a particular building should be based on the condition of the windows in that building. Table 2 shows the Equivalent Leakage Area (ELA) for the pre-treatment baseline windows based on sash leakage and ELA based on 30 percent of rough opening leakage assumed to come from outside. ELA is the area of a single hole that would have the same air leakage as the aggregate of all the air leakage sites in a window. First year heating cost is shown for infiltration, non-infiltration and the total of these two components of heat loss.

Results for windows retaining original sash.

Table 3 lists and describes upgrades that retained the original sash. Figure 5 shows the heating cost due to air leakage for these upgrades. Leakage rates are shown without storm windows to emphasize the differences, which are somewhat
Table 2. ELA for Baseline Windows - Original (Pre-treatment) Condition.

<table>
<thead>
<tr>
<th>Baseline Window Category (in³)</th>
<th>ELA Sash (in³)</th>
<th>ELA Rough Opening (in³)</th>
<th>ELA Total</th>
<th>First year Cost for Air Leakage</th>
<th>First yr. Cost for Non-Air Leakage</th>
<th>Total Heating Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tight Window</td>
<td>0.27</td>
<td>0.59</td>
<td>0.86</td>
<td>$2.09</td>
<td>$12.31</td>
<td>$14.40</td>
</tr>
<tr>
<td>Typical Window</td>
<td>0.89</td>
<td>0.59</td>
<td>1.48</td>
<td>$3.59</td>
<td>$12.31</td>
<td>$15.90</td>
</tr>
<tr>
<td>Loose Window</td>
<td>2.19</td>
<td>0.59</td>
<td>2.78</td>
<td>$6.69</td>
<td>$22.21</td>
<td>$28.90</td>
</tr>
</tbody>
</table>

Figure 4. Selected window energy upgrades.
Table 3. Upgrades Retaining Original Sash.

<table>
<thead>
<tr>
<th>Site ID</th>
<th>n</th>
<th>Upgrade Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>7</td>
<td>Vinyl jamb liners; no weather stripping</td>
</tr>
<tr>
<td>13</td>
<td>8</td>
<td>Vinyl jamb liners; silicone bulb weatherstripping at sill and head</td>
</tr>
<tr>
<td>7</td>
<td>19</td>
<td>Vinyl jamb liners; silicone bulb weatherstripping at sill, head, and meeting rail</td>
</tr>
<tr>
<td>2</td>
<td>3</td>
<td>Vinyl jamb liners; silicone bulb weatherstripping at sill, head, and meeting rail; double-pane insulating glass; new latch at meeting rail (Bi-Glass System)</td>
</tr>
<tr>
<td>17</td>
<td>3</td>
<td>Zinc rib-type weatherstripping on lower sash; upper sash painted in place; V-strip weatherstripping at meeting rail; pulley seals; new aluminum triple track storm windows, frames caulked in place</td>
</tr>
<tr>
<td>19</td>
<td>2</td>
<td>Bronze V-strip weatherstripping on lower sash, meeting rail, and sill junction; top sash painted in place; existing aluminum triple track storm window caulked in place; no locking mechanism</td>
</tr>
<tr>
<td>10</td>
<td>1</td>
<td>Sash weatherstripped with Q-Lon between sash face and parting bead; Polyflex Vee with Tee-slot at sill, head, and meeting rail junctions</td>
</tr>
</tbody>
</table>

masked by the use of storm windows. An extremely wide variation in the cost of air leakage for the first four sites listed — all of which utilized vinyl jamb liners — appears attributable to the role that workmanship plays in the success of jamb liners at reducing air leakage. Jamb liners require a precise fit of the sash to the liner and opening to avoid air leakage around the jamb liner and between liner and sash. Windows where the jamb was out of square were difficult to seal and did not perform well. Also, although sites seven and two incorporated weatherstripping at the meeting rail, an important location, the much lower leakage rate should not be attributed only to that difference.

At site 17, metal weatherstripping was fixed to the jamb with a flange that fits into a slot milled in the sash, V-strip at the meeting rail, and caulked upper sash, which resulted in quite low sash leakage. However, the total leakage was approximately the same as sites seven and two, due to high leakage through the rough opening. Similarly, even though site 10 had a very low sash leakage rate, the overall air leakage performance was undermined by the rough opening air leakage.

Figure 6 shows one total first year heating cost for these upgrades, and identifies the costs for sash leakage, rough opening air leakage and non-infiltration losses. It quickly becomes apparent that infiltration is a small part of the heating cost. Nonetheless, differences in infiltration performance result in as much as a $5 per year per window difference in heating costs.

Results for storm windows. Table 4 shows reduction in leakage area due to the installation of new or rehabilitated storm windows. Results for the first four windows demonstrate the wide variability in prime window leakage and the variety in air leakage reduction performance of a variety of storm windows. Site 14, for example, used a type of storm window with a laboratory tested air leakage rate of 0.01 standard cubic feet per minute per linear foot of crack (scfm/lfc), an extremely low leakage rate. This shows the importance of looking for and specifying storm windows with low air leakage rates, based on independent laboratory testing. Caulking exterior storm frames to the trim at site 19 also resulted in lower leakage and should be routinely specified.

Interior storm windows have the advantage of reducing air leakage through the rough opening as well as through the sash. They accomplish this by reducing the flow of air that can come through the window-weight cavity/rough opening and then through the pulley or other jamb opening to the interior of the prime window.

Figure 7, First Year Heating Cost per Window for Storm Windows Open and Closed, shows the cost for heat losses due to air leakage and those due to non-infiltration losses. In this context it becomes clear that while infiltration is the much smaller component of window heating costs, it can be a significant part of the total costs for windows, particularly those without storm windows. It is also clear that the first year heating costs are similar for all storm window
First Year Heating Cost for Infiltration Only
Upgrades Retaining Sash, Without Storm Windows

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Upgrade Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>7 Vinyl jamb liners; no weather stripping</td>
</tr>
<tr>
<td>13</td>
<td>8 Vinyl jamb liners; silicone bulb weatherstripping at sill and head</td>
</tr>
<tr>
<td>19</td>
<td>9 Vinyl jamb liners; silicone bulb weatherstripping at sill, head, and meeting rail</td>
</tr>
<tr>
<td>2</td>
<td>3 Vinyl jamb liners; silicone bulb weatherstripping at sill, head, and meeting rail; double-pane insulating glass; new latch at meeting rail (Bi-Glass System)</td>
</tr>
<tr>
<td>17</td>
<td>3 Zinc rib-type weatherstripping on lower sash; upper sash painted in place; V-stripe weatherstripping at meeting rail; pulley seals; new aluminum triple track storm windows, frames caulked in place</td>
</tr>
<tr>
<td>19</td>
<td>2 Bronze V-stripe weatherstripping on lower sash, meeting rail, and sill junction; top sash painted in place; existing aluminum triple track storm window caulked in place; no locking mechanism</td>
</tr>
<tr>
<td>10</td>
<td>1 Sash weatherstripped with Q-Lon between sash face and parting bead; Polyflex Vee with Tee-slot at sill, head, and meeting rail junctions</td>
</tr>
</tbody>
</table>

Figure 5. First Year Heating Costs, Infiltration Only, Upgrades Retaining Sash.

Total First Year Heating Cost
Upgrades Retaining Sash, With Storm Windows

<table>
<thead>
<tr>
<th>Site ID</th>
<th>Upgrade Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>12</td>
<td>7 Vinyl jamb liners; no weather stripping</td>
</tr>
<tr>
<td>13</td>
<td>8 Vinyl jamb liners; silicone bulb weatherstripping at sill and head</td>
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<tr>
<td>17</td>
<td>3 Zinc rib-type weatherstripping on lower sash; upper sash painted in place; V-stripe weatherstripping at meeting rail; pulley seals; new aluminum triple track storm windows, frames caulked in place</td>
</tr>
<tr>
<td>19</td>
<td>2 Bronze V-stripe weatherstripping on lower sash, meeting rail, and sill junction; top sash painted in place; existing aluminum triple track storm window caulked in place; no locking mechanism</td>
</tr>
<tr>
<td>10</td>
<td>1 Sash weatherstripped with Q-Lon between sash face and parting bead; Polyflex Vee with Tee-slot at sill, head, and meeting rail junctions</td>
</tr>
</tbody>
</table>

Figure 6. Total First Year Heating Cost, Upgrades Retaining Sash.
Table 4. Reduction in Equivalent Leakage Area (ELA) by Storm Window Upgrades.

<table>
<thead>
<tr>
<th>Storm Location</th>
<th>Site ID</th>
<th>n</th>
<th>Storm Window Type</th>
<th>Total Window ELA</th>
<th>% Reduction</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Storm Window Type</td>
<td>Storm Open</td>
<td>Storm Closed</td>
</tr>
<tr>
<td>Exterior</td>
<td>10B</td>
<td>1</td>
<td>Triple Track, new</td>
<td>4.6</td>
<td>0.64</td>
</tr>
<tr>
<td></td>
<td>14AD</td>
<td>4</td>
<td>Triple Track, new</td>
<td>1.8</td>
<td>0.43</td>
</tr>
<tr>
<td></td>
<td>17</td>
<td>3</td>
<td>Triple Track, new</td>
<td>1.1</td>
<td>0.91</td>
</tr>
<tr>
<td></td>
<td>19</td>
<td>2</td>
<td>Triple track, existing, caulked</td>
<td>0.7</td>
<td>0.61</td>
</tr>
<tr>
<td></td>
<td>10C</td>
<td>1</td>
<td>Fixed upper, removable lower</td>
<td>4.3</td>
<td>0.86</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>1</td>
<td>Exterior Wood, new</td>
<td>2.2</td>
<td>1.7</td>
</tr>
<tr>
<td>Interior</td>
<td>14EF</td>
<td>2</td>
<td>Triple Track, new</td>
<td>3</td>
<td>0.48</td>
</tr>
<tr>
<td></td>
<td>10A</td>
<td>1</td>
<td>Spring-loaded frame w/ WS</td>
<td>4.3</td>
<td>0.39</td>
</tr>
<tr>
<td></td>
<td>15</td>
<td>3</td>
<td>Plexi w/magnetic strip</td>
<td>2.2</td>
<td>0.22</td>
</tr>
<tr>
<td></td>
<td>10-le</td>
<td>0</td>
<td>Spring-loaded frame w/ WS, low-e</td>
<td>**</td>
<td></td>
</tr>
</tbody>
</table>

** Not encountered in field. Air leakage data from 10A used.

Table 5. First Year Heating Cost for Upgrades that Replace the Original Sash.

<table>
<thead>
<tr>
<th>Site ID</th>
<th>n</th>
<th>Upgrade Description</th>
<th>First Year Heating Cost</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Non-Infiltration</td>
<td>Infiltration</td>
</tr>
<tr>
<td>6</td>
<td>6</td>
<td>Vinyl Window Insert</td>
<td>$12</td>
<td>$0.37</td>
</tr>
<tr>
<td>11</td>
<td>6</td>
<td>Wood Window Insert</td>
<td>$12</td>
<td>$0.70</td>
</tr>
<tr>
<td>3BCD,12B</td>
<td>7</td>
<td>Replacement Sash + Storm</td>
<td>$12</td>
<td>$1.68</td>
</tr>
<tr>
<td>13I</td>
<td>1</td>
<td>Replacement Sash+Storm, poor fit</td>
<td>$12</td>
<td>$4.83</td>
</tr>
<tr>
<td>18</td>
<td>2</td>
<td>Marvin insulated glass Rplcmnt Sash</td>
<td>$12</td>
<td>$0.60</td>
</tr>
<tr>
<td>18-le</td>
<td>0</td>
<td>Marvin insulated Low-E Rplcmnt Sash</td>
<td>$5</td>
<td>$0.60</td>
</tr>
</tbody>
</table>

strategies, unless low-e glass is used for the storm, in which case the first year energy use is approximately $5 lower. 10-le uses the same site data as site 10A, but assumes the use of low-e glass. (It should be noted that glass manufacturers have made substantial progress in producing low-e glass that retains its heat reflecting properties while avoiding color distortions of early examples of this technology.) In general, storm windows cut the energy usage of the windows nearly in half.

Results for replacement sash and window inserts. Table 5 lists the sites with either replacement sash or window inserts. Costs for infiltration and non-infiltration losses are shown in this table and in Figure 8. With two exceptions, the first year heating costs are similar, ranging from $12 to $14. Window 13I was poorly installed in a frame that was out of square, resulting in high sash leakage and associated heating costs. This example indicates the importance of square-ness of the opening when installing new square sash. Site 18-le uses the air leakage data from site 18, but assumes a non-infiltration loss that would be achieved with a similar window with low-e glass. The savings of low-e glass over other sash replacement strategies is estimated at $3.40 per year.

Summary of results for all treatment types. Figure 9 indicates the infiltration and non-infiltration first year heating costs for groupings of window upgrade types, and for the three baseline windows. It is notable that heating costs are similar for most rehabilitated windows, with the exception of treatments using low-e glass, which have lower heating costs. Further, while infiltration is of secondary importance, it is not insignificant.
Figure 7. First Year Heating Cost per Window, Storms Open and Closed.

Figure 8. First Year Heating Cost per Window, Upgrades that Replace Sash.
Figure 9. First Year Heating Cost per Window, Pre- and Post-Treatment.

Table 6. Costs and first year heating cost savings for window upgrade categories.

<table>
<thead>
<tr>
<th>Category</th>
<th>Upgrade *</th>
<th>Cost</th>
<th>Cost with Lead Abatement**</th>
<th>First Year Savings Compared to Baseline Windows****</th>
</tr>
</thead>
<tbody>
<tr>
<td>Retain original sash</td>
<td>Vinyl jamb liners Weatherstripping</td>
<td>$175</td>
<td>$300</td>
<td>**</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$75</td>
<td>$200</td>
<td>$0.20</td>
</tr>
<tr>
<td>Replace Sash</td>
<td>Single glass sash Window inserts Low-E DG inserts</td>
<td>$200</td>
<td>$200</td>
<td>$0.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$250-$500</td>
<td>$200-$500</td>
<td>$1.90</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$250-$550</td>
<td>$250-$550</td>
<td>$5.30</td>
</tr>
<tr>
<td>Storm Windows</td>
<td>New exterior New interior Interior low-E</td>
<td>$100</td>
<td>$225</td>
<td>$1.00</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$115</td>
<td>$240</td>
<td>$1.30</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$155</td>
<td>$280</td>
<td>$4.70</td>
</tr>
</tbody>
</table>

* All upgrades retaining original sash and single glass replacement sash include retaining existing storm windows. Costs for replacement sash varied from medium cost vinyl insert windows to high quality wood inserts.

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

*** No savings realized.

**** Savings are based on 7744 degree days, oil heat at $0.90/gallon with 75% overall heating season efficiency. Note that the samples of most of the upgrades tested were very small, and that, in most cases, these results have very low statistical significance.
Analysis of Results

Comparison of costs and savings. Table 6 compares costs and savings for major groupings of window upgrades. Costs and savings for this table are averages based on a number of upgrades tested in each category. Note that the upgrade assumes the storm window is in place, unless the upgrade includes insulated glass. One immediate conclusion to be drawn from this table is the importance of which components of an upgrade are chosen for comparison with the value of energy savings. Should the whole cost of the upgrade be compared to the savings? Or should part of the costs of upgrades be attributed to maintenance, ease of operation of the window, occupant comfort or other considerations? The answer will depend on the particular circumstance. One approach is to consider the difference between the costs of routine maintenance and the costs for an upgrade that would provide lower heating costs, and to compare this difference to the energy savings. Financing costs, cash flow analysis and life-cycle costing are also important considerations. The costs and value of potential window energy savings relative to other energy conservation measures are also important within the often constrained building rehabilitation budgets. These considerations were beyond the scope of this study.

Table 6 compares heating cost savings to the heating costs associated with a baseline window similar to the windows being considered for upgrade. If the original window already has a low air leakage rate and has a storm window in place (Tight), most upgrades result in very low energy savings. Compared to the Typical baseline, most upgrades result in savings ranging from $1 to $7 in the first year. Compared to the baseline window without a storm window (Loose), savings range from $14 to $20 in the first year.

It is important to consider the costs in context. For example, the costs for upgrading a Loose window with weatherstripping, sealing the top sash, and rehabilitating an existing storm are $75, if no lead abatement is needed, which compares favorably with the first year savings of $15. If lead abatement were needed in addition to weatherstripping, the cost would be $200, similar to the cost for replacement sash, since no lead abatement would be needed in that case. Savings for the replacement sash are similar, but the replacement sash might offer greater ease of operation. A new exterior storm window added to a Loose baseline window has a first year savings of $16 at a cost of $100 (excluding lead abatement), a 16 percent rate of return in the first year. Adding a low-e interior storm saves $19 at a cost of $155, a 12 percent rate of return in the first year. Savings compared to total costs for upgrades of Typical baseline windows offer very low rates of return, and returns are even lower for Tight baseline windows. While some savings are low compared with total costs in many cases, the basis for comparison must be carefully considered.

Energy savings due to increased occupant comfort are not included in this study. These can be significant: if an occupant can lower the air temperature as a result of warmer interior window surface temperatures and decreased drafts due to air leakage, significant heating savings can result. Likely occupant interaction with the window upgrade is also not considered: a significant fraction of storm windows can be found open all winter in some buildings. These considerations emphasize the need for a full energy analysis to put window savings in the proper context of a building rehabilitation project, and to take full and appropriate account for costs and savings.

Decisions related to the upgrade of windows should be made primarily for reasons other than energy savings: for a given set of initial conditions, there is not a large difference between the energy savings for different options. Non-energy rationale for choosing a particular rehabilitation strategy can be based on historic considerations, occupant comfort, long term maintenance costs, lead abatement issues, egress requirements, durability of the energy improvements, total building rehabilitation budget, and matching the type and ease of window operation with the occupant population.

Once the window replacement strategy is chosen, energy should be considered and incremental costs and incremental savings should be compared. For example, purchasing low-e glass in place of clear glass typically has a $17 to $40
incremental cost for a storm window or for double glazing. With savings of approximately $3.5 in the first year (excluding savings from a lowered thermostat due to warmer mean radiant temperature), this results in a 10 to 20 percent rate of return. Improved treatment of rough opening extraneous leakage can often be accomplished at a low cost, and can result in improved occupant comfort. The value of warmer interior surfaces and fewer drafts can be considered in the context of whole-building energy analysis.

Further Research
Several useful areas for further research became apparent during the course of this study:

- Study a more statistically significant sample, particularly of promising upgrade strategies
- Develop a method to more accurately quantify rough opening leakage
- Develop and field test methods to reduce rough opening leakage
- Develop better methods to correlate visual observation with expected air leakage rate
- Document how energy performance changes over time – durability of various treatments
- Investigate ease of operation of various upgrades
- Investigate storm windows relative to code compliance, particularly egress issues
- Perform controlled laboratory studies on a wider variety of treatments
- Investigate the interaction between infiltration and non-infiltration losses
- Research other rehabilitation strategies
- How often are storm windows REALLY open?
- Investigate applications of low-e glass products that minimize visual impact
- Work collaboratively with product manufacturers and preservationists to improve energy performance of products and applications

Conclusions: A summary of advice for preservationists

Decisions about window upgrade methods should be based primarily on decisions other than energy: Most energy-related window projects, including window retention and window replacement, result in similar post-treatment energy usage.

Once a general rehabilitation strategy is chosen, energy performance of that rehabilitation should be optimized. For example, low-e glass can reduce energy usage below average.

The level of treatment should be matched to the original condition of the window. To prioritize window treatment appropriately, diagnostic whole-building air leakage testing should be used to guide air leakage reduction strategies as a part of a total building energy analysis.

"Retain versus retire" is a false dichotomy: window energy rehabilitation encompasses a continuum of possibilities:

1. Retain and repair original material only.
2. Retain and repair original material and add a storm window.
3. Retain and repair original material and add weatherstripping.
4. Retain but modify sash to accommodate vinyl channels and/or let-in weatherstripping.
5. Retain sash, but modify to accommodate double glass (can be low-e), vinyl channels, and let-in weatherstripping.
6. Replace sash with single glass sash, with varying levels of vinyl channels and weatherstripping.
7. Replace sash with double-glazed sash (can be low-e), with varying levels of vinyl channels and weatherstripping.
8. Remove sash and insert a replacement window inside existing jamb, including new jambs.
9. Remove entire window and trim and replace with a new window.
All possibilities can include storm windows, and options 3-8 should include sealing and insulating window weight/rough openings.

Quality of workmanship is a large determinant in final air leakage rate.

The rough opening, as well as the sash and jamb, should be treated to minimize air leakage.

In general, air leakage is the smaller part of the total heat loss of a window with two layers of glass. Lowering non-infiltration losses, by using double glass and low-e glass, results in greater energy savings than lowering air treatment leakage losses. Effective window upgrades reduce both losses.

Storm windows should be specified with low, independently-tested air leakage rates. Exterior storm frames should be caulked to outside trim.

Interior storm windows not only reduce leakage around the sash, but reduce leakage through the rough opening.

Infiltration reduction can significantly improve occupant comfort, which can result in lower thermostat setting and associated heating energy savings not reflected in this study.

Low-e glass, by raising interior glass surface temperatures, increases occupant comfort and can also result in similar savings not reflected in this study. Recent improvements in low-e glass have minimized its visual impact.

Notes

1 Non-infiltration losses consist of radiation and convection to the interior surfaces of the window from the room, conduction through the materials of the window, and convection and radiation from the exterior surfaces to the outdoors.

2 This model was developed for estimating natural infiltration rates for buildings based on whole building air leakage testing. Sensitivity analyses performed indicated that application of the model to single window data resulted in very similar results as the difference in modeled whole building natural infiltration rate with and without the window. A 3,000 square foot, two-floor, four-unit apartment building, typical of affordable housing in Vermont, with typical wind shielding, was used for this modeling.

3 This study used the simplifying assumption that natural infiltration through a window with a storm window and a prime window does not alter the conductive and convective heat transfer in that region. Investigating this interaction was beyond the scope of this project, so it was assumed that these heat loss paths were independent.

4 This leakage rate was as tight as any window tested in the study. The spring-loaded interior storm sash, site 10A, also had a low sash leakage rate of 0.05 scfm/ft² (at 0.30 inches water pressure.) The magnetic strip/plexiglass interior storms at site 15 had a sash leakage rate of 0.01 scfm/ft².

5 Low-emissivity (low-e) glass has a special coating that reduces heat radiation emitted by the surface by as much as 90 percent, improving the U-value of double glass windows by approximately 30 percent.

Bibliography


In historic buildings, windows are arguably the least maintained and most neglected exterior facade component. Many building occupants simply accept that older windows perform poorly. However, neglect and lack of maintenance of windows does have consequences. After prolonged neglect, windows will deteriorate beyond the point where repair and maintenance are feasible. Therefore, it should be a regular practice in older and historic buildings to periodically evaluate the windows to determine their condition.

Window Evaluation Program

There are many criteria used to evaluate the condition and performance of existing windows. Windows in historic buildings can present additional concerns that are not typically considered during the evaluation of windows in newer buildings. Some criteria used to evaluate existing windows include:

- water penetration
- air infiltration
- structural integrity
- corrosion
- anchorage conditions
- deterioration of sash and frame components
- condition of surrounding construction
- thermal performance
- presence of lead-based paint
- condition of glazing
- condition of sealants
- glass breakage

- window operation
- window hardware

Criteria used to evaluate existing windows will vary depending on the geographic location of the building and on the location of a window within a building. A window in Miami will not be required to perform the same as a window in Chicago. Likewise, a window protected under a projecting cornice will not be required to perform in the same way as an exposed window at the corner of a building.

However, regardless of the location of the window, any window evaluation program is likely to review similar overall conditions. Different approaches for window evaluations are often used, but window evaluation programs typically include the following three basic elements as a minimum:

- Document review
- Visual inspection and documentation of windows
- Field performance testing

Document Review

Original building drawings and specifications can be an invaluable tool for understanding the construction of the windows in the exterior facade. For older and historic buildings, copies of original building drawings and specifications may not be available. Other documents that can be reviewed include window shop drawings, previ-
ous consultant’s reports, water leakage surveys, previous facade repair documents, and energy bills.

**Visual Inspection and Documentation**

Visual inspection and documentation of existing windows is very important in a window evaluation program. First, the various types of windows in the building should be determined. Then, existing windows should be inspected in detail. Naturally, it is best to inspect each window in the building. For large buildings, however, a representative sample of windows can be sufficient for identifying common window problems.

The detailed window inspection should include an evaluation of the existing condition of window components, such as sash and frame materials, hardware, glass, glazing, sealants, and finishes. The windows should also be operated to evaluate whether they open and close easily, and if they close and lock completely. Older windows, especially hung-type windows, often do not fully close to the point where the locking hardware can properly engage.

Other relevant information can be obtained during a window inspection. The size of the window and the number of divided lights is useful data to obtain. The surrounding construction should be inspected to look for signs of water leakage or other types of distress that could indicate problems with the existing windows. Also, it is useful to document the locations of window air conditioner units or other elements that penetrate a window opening, such as HVAC or electrical lines. Obstructions to existing windows, such as built-ins or equipment, should also be noted during the inspection. If previous repairs were performed on the windows, these should be documented during the inspection. A sample of a window survey sheet is included as Figure 1.

**Field Performance Testing**

Field performance testing is useful to provide quantitative data on the various performance characteristics of the existing windows. Standardized and customized field tests can be performed, depending on the information required and on conditions at specific windows. Field tests can be performed to evaluate the following window characteristics:

- Water penetration performance
- Air infiltration performance
- Structural performance
- Thermal performance
- Sound transmission
- Window operating force

The types of tests that are selected for a window evaluation program will vary depending on the goals of the program. For example, it may not be necessary to evaluate the structural performance of an existing window at a two-story residential structure, but it may be important to include structural performance testing in the evaluation of existing windows in a high-rise structure.

Window conditions and testing conditions will vary at different windows within a building. Therefore, a number of windows should be tested to obtain a representative sampling of window performance. The number of windows to be tested will be different for each building depending on the size of the building, number of windows, number of different installation conditions, number of window types, variations in the condition of existing windows, and on the individual performing the window evaluation program.

Selection of windows to be tested can have an important impact on the results of the window evaluation program. For establishing overall performance data for windows in the building it is important to select windows with conditions typical of the majority of windows in the building. If testing is being performed to evaluate specific window conditions, then it must be determined beforehand which windows have the conditions desired to be tested. For example, it may be beneficial to establish a value for air infiltration through a window that does not fully close and lock.

Field performance testing is also a useful tool to evaluate the effectiveness of repairs implemented at existing windows. To evaluate the effectiveness of repairs, performance testing should be performed at a window before and after repairs are made. The results of the testing can then be
compared to determine the effectiveness of the repairs.

Field Performance

The most common complaints with existing windows include difficulty of operation, excessive air infiltration, and water leakage. Difficult window operation affects the building occupant’s ability to properly utilize the windows. If windows do not open or close properly, they cannot fully provide light and ventilation to an interior space. Poor window operation also affects the air infiltration and water penetration performance of the windows, since a window that does not properly close will have gaps that will allow air and water to leak to the interior. The scope of this paper is limited to the evaluation of the field performance of existing windows with respect to air infiltration and water penetration.

Standardized test methods are available for use in performing field tests of windows. The standardized test methods were established by window 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 industry associations have also established minimum performance standards for evaluating the performance of installed windows. The American Society for Testing and Materials (ASTM) has adapted many of the testing procedures developed by the industry associations as standard test methods.

It is important to mention that the standardized test methods were developed to evaluate the field performance of newly installed windows. The minimum performance standards developed by the industry associations are based on the standardized tests. Therefore, standardized test parameter values for test pressure, test duration, and water flow rate have been established. However, when using the standard test methods for evaluating the performance of existing windows, it may be beneficial to modify the test parameters for specific circumstances, such as those discussed below.

While these standards are intended to apply to newly installed windows, they serve as benchmarks for existing windows as well. If a window evaluation program includes a decision to be made between window repair and window replacement, the industry standard performance criteria for new windows may be selected as the standard for evaluation of the repaired windows. The repaired windows may be required to perform to these standards to be considered a viable alternative to window replacement. Many building owners consider this a valid comparison because they are not willing to sacrifice performance. While water penetration and air infiltration performance are important criteria in the evaluation of existing windows, other important criteria, such as those listed above, should be considered.

Water Penetration

Water leakage through windows is problematic for a few reasons. First, water leakage can stain or damage interior furnishings and belongings. Second, leakage can allow water to enter the construction of the exterior walls and floors, which can lead to deterioration of these components if allowed to continue for a period of time. Water leakage can also lead to health concerns in buildings because it promotes the growth of molds in interior spaces and within hidden wall and floor construction assemblies. For these reasons, no amount of water leakage is acceptable through windows.

Standardized field water penetration test methods include:

- ASTM E1105 - 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 501.2 - Field Check of Metal Storefronts, Curtain Walls, and Sloped Glazing Systems for Water Leakage

ASTM E1105

ASTM E1105 involves spraying water on the outside of the window while simultaneously applying a uniform or cyclic application of pressure to one side of the window, typically the
interior side to create a lower pressure on the interior side of the window. The water is typically sprayed on the exterior through a grid of evenly spaced spray nozzles that provide a uniform coverage of water over the surface of the window. The water flow rate is specified to be 5 gallons per hour per square foot of test area. This water flow rate corresponds to a rainfall rate of about 8 inches per hour, which is not uncommon for rainfalls of short duration in many parts of the United States.

The pressurized test chamber is typically constructed on the interior of the window. Negative pressure is created by drawing air from the chamber. The negative pressure is introduced to attempt to draw water through the window to the interior, thus simulating a wind-driven rain. The pressure that is introduced in the chamber can be correlated to an approximate wind velocity. For example, an industry standard test pressure for new windows is 6.24 pounds per square foot (psf), which corresponds to a wind velocity of about 50 miles per hour (mph).

Most often, the purpose of performing water penetration tests at existing windows in historic buildings is to evaluate the existing performance of the window and not to determine if the window meets industry standard requirements. Therefore, it is often beneficial to vary the standardized test duration and the test pressure. It is the author's experience that existing windows with a water leakage problem will leak during a water penetration test with no chamber pressure. It is very useful to begin a water test at a window with no chamber pressure and to run the test for the standard 15 minute duration. Then, after 15 minutes, the pressure is increased to about 1.57 psf, or 25 percent of the standard test value. The pressure is continued to be increased in increments of 1.57 psf until the window fails by leaking.

It is recommended to start with no pressure and slowly increase pressure until failure because this allows the window evaluator to determine more easily the mode of failure and the threshold for failure. For example, a window might experience a glazing leak at no pressure, but might overflow at the sill at a pressure of 5 psf. If the test begins at a pressure of 6.24 psf, it would be difficult to determine where the water leak comes from. It is important to verify the source(s) of water leaks so that an evaluation can be made regarding appropriate repairs.

AAMA 501.2
AAMA 501.2 is a test performed with a single, hand-held, calibrated water spray nozzle. The test is useful for identifying specific sources of water leaks at windows. It is beneficial to use this test method to accompany the ASTM E 1105 test method to identify leaks observed during the test method. This test method is a qualitative procedure, as opposed to the quantitative ASTM E 1105 test method.

The test method calls for a specific spray nozzle head and a specific water pressure in the range of 30-35 pounds per square inch (psi). Water is sprayed on the window from the exterior, and someone is on the interior to observe for water leakage. The test involves progressively wetting the window joints, beginning at the bottom of the window and working upward until all desired joints are tested.

While performing this test method, it is often tempting to begin testing at locations where a water leakage source appears obvious. However, the reason it is important to test by working from the bottom upward is that care must be taken not to wet window joints that have yet to be tested. Water leaks often show up at the bottom of windows, even though the source may be above. If the test was started at the top of the window, water would wet all joints below, making it much more difficult, if not impossible, to accurately verify a water leakage source.

Air Infiltration
All windows leak air. Some windows leak more air than others, depending on the type of window operation, the condition of the window and weatherstripping, and the location of the window in the building. Excessive air infiltration through windows affects the comfort of building occupants. Windows that leak a large quantity of air on cold winter days, for example, will make the interior space feel much colder. Air infiltration also has an impact on the amount of energy required to heat and cool the building.

As an example, for a typical bedroom of 120
square feet in area, with a 9 foot high ceiling, the volume of the space is 1,080 cubic feet. Assume that the bedroom has two double hung windows that are 4 feet wide by 6 feet high, and that these windows have each been determined to leak 9 cubic feet of air per minute (cfm). On a cold winter day, the heating system for this room would be required to heat one air change, or the total volume of the room, every hour. If the windows were repaired so that the air infiltration was reduced to the industry standard of 0.15 cfm per linear foot of sash crack, for a total of 3.6 cfm, the heating system would be required to heat 0.4 air change per hour, which is a savings of 60 percent. It is important to note that while this is a significant energy savings, heat loss from air infiltration is only a part of the total heat loss through the building envelope. Heat loss also occurs through walls, roofs and floors.

To measure the air infiltration through installed windows, a standard test method has been developed: ASTM E 783-91 - Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors. This test method is performed by applying a uniform pressure to one side of the window to create a lower pressure on the interior side of the window. The pressurized test chamber is typically constructed on the interior of the window. Negative pressure is created by drawing air from the chamber. The negative pressure is introduced to simulate a given set of natural environmental conditions. Typically, the test chamber used for the air infiltration test is also used for the water penetration test.

To perform an air infiltration test, the exterior of the window is masked to prevent air from passing through it. The amount of air flowing through the test chamber at a given pressure is then measured and recorded. Next, the masking is removed, and the amount of air flowing through the chamber at the same test pressure is measured and recorded. The difference between the two numbers is the air infiltration through the window only.

The industry standard for air infiltration has been set at a test pressure of 1.57 psf for lower performance windows and 6.24 psf for high performance windows. The standards are typically expressed as cfm per linear foot of sash crack for operable windows, and cfm per square foot of window area for fixed windows. As discussed above, the industry standards have been established for newly installed windows but are useful benchmarks for comparing the performance of existing windows to the requirements for new windows.

As for water penetration tests, it is often useful to proceed with test pressures at small increments to obtain more data on the performance of the windows. The increments to be used should be selected based on the performance of the windows and on the capacity of the testing equipment. Typically, windows in older and historic buildings will have far greater air infiltration than new windows, while the water penetration performance of the older windows will not be much below the performance of new windows.

Miscellaneous Tests
There are useful modifications to the standardized tests that can be performed to better determine the performance of existing windows. To help pinpoint water leakage sources, window sashes or other window joints can be masked or isolated so that they are excluded from the test. Masking should be performed prior to the start of testing. As testing proceeds, specific window joints can be unmasked so that they are tested. This iterative process of masking and unmasking will enable the window evaluator to specifically locate problem conditions with the windows.

Masking can also be used during air infiltration tests to determine the sources for the greatest air infiltration. Window sash joints can be individually masked and unmasked during iterative testing to obtain air infiltration data for conditions when different joints are tested. Using masking, the window evaluator can, for example, identify the weatherstripping in the sash that most contributes to the overall air infiltration of the window.

There are other miscellaneous water penetration tests that can be performed to provide useful information during a window evaluation program. One test that can be performed on windows with a subsill is to flood the subsill and observe if water leakage occurs from the subsill. This test can be done by plugging the exterior weepholes in the subsill and pouring water into the subsill.
Water is typically allowed to stand in the subsill for a period of about 15 minutes, during which time the area beneath and at the ends of the subsill are observed for water leakage.

Conclusions

Field performance testing is a useful component of a window evaluation program that provides qualitative and quantitative information on the performance of existing windows. Air infiltration and water penetration tests are the most commonly performed field tests. Industry standard performance requirements can be used to compare the performance of existing windows to the requirements for new windows. Industry standard test methods are often modified when testing existing windows to obtain more specific window performance information that is useful in evaluating the condition of windows. Miscellaneous tests can also be performed to obtain specialized information for a particular condition.

Bibliography


WINDOW SURVEY SHEET
XYZ BUILDING, 1234 FIFTH STREET, HOMETOWN, STATE

SUITE: _________ ELEVATION: _________ WINDOW: _________
DATE: _________ DIVIDED LITES: _________ BY: _________

PD Plaster damage
DM Deteriorated exterior masonry
IPC Interior paint deterioration
SD Sealant deterioration
STC Stop corrosion
CL Corroded steel lintel/shelf angle
GD Glazing compound deteriorated/missing
WG Wired glass
SO Sash operation difficult/won’t open
SL Sash lock damaged/missing/not engaging
WD Weatherstrip deteriorated
WS Water stains
DC Deteriorated exterior concrete
XPC Exterior paint deterioration
SAC Sash corrosion
FC Frame corrosion
CSL Corrosion section loss
GB Glass cracked/broken
SC Sash won’t fully close
PM Sash pull hardware missing
AD Air deflector
WM Weatherstrip missing

(Note: Place an "X" before a code for conditions observed on exterior.)

REMARKS:

________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________
________________________________________________________________________

Figure 1.
Music in the ears of window industry insiders: insulating glass (IG) units, low-emissivity coatings, inert gas fills, multiple glazing layers and films, warm edge spacers. For professionals working to protect the character of historic buildings, however, this list of products and technologies can have an ominous ring. Schooled in the principles of minimum intervention and caution, preservationists may hesitate to impose new technology into existing window assemblies.

A sound awareness of potential benefits and risks is essential in making informed choices about window retrofitting. Restoration projects can strike an appropriate balance between thermal performance and historic authenticity. Certain of the new technologies lend themselves to retrofit applications, while others are technically compromised by being forced into an existing assembly. Drastic retrofit techniques which do not repay the cost of their implementation, or which cannot sustain the initial improvement in thermal performance, should not be considered, particularly when historic fabric is altered in the process.

Common approaches will be analyzed in terms of physical/visual impact, technical challenges, impact on performance, costs, and long term prognosis.

Adding Weatherstripping and Secondary Glazing

A window is intended to provide a plane of airtightness within the wall opening. When it does not, infiltration and exfiltration through perimeter cracks at the interface of glass and rebate, sash and frame, and frame and rough opening can be a major source of heat loss.

Even when a window is relatively air-tight, the cold glass surface chills the air that contacts it, causing convection currents as the denser cold air falls to the floor. Perceived as a "draft," this condition will not be corrected by air-sealing the opening. Similarly, when warm moist interior air comes in contact with cold panes, the cooled air is less able to support its moisture content, which condenses on the glass. The solution is to promote a warmer glass surface by adding glazing and air layers to insulate between interior and exterior temperatures. Traditional storm windows, modern "energy panels" at the interior or exterior face of the opening, or sull sash (sash fitted with two layers of glass that are not hermetically sealed) are all variants of non-sealed double glazing.

Note that while two layers of glass may be considered de rigueur for comfort and condensation resistance in residential buildings, this may not be strictly necessary for commercial or institutional buildings.

Physical/Visual Impact

- Not all traditional buildings were designed to have interior or exterior storm windows, which even when nicely detailed will alter the visual relationship between the original glazing plane and the interior or exterior wall for at least part of the year. With metal and PVC versions, a neutral appearance is the best that can be hoped for.
Turning single glazed sash into sull sash requires recessing the additional glass layer into the face of the sash to permit the sash to slide past each other. A rebate 3/8 inch deep by 1/2 inch wide must be routed into the moulded edge of stiles and rails; muntins, when present, will also have be cut back 3/8 inch. In terms of structural integrity, this loss of material can be unacceptable for finer joinery; aesthetically, it is particularly objectionable for sash with muntins. The additional weight of the glazing layer will require adjustment of balancing mechanisms. While acrylics are lighter, glass has a more durable surface.

Technical Challenges
- The optimum space between glazing layers is 1/2 inch, however traditional reveals, hardware positions and offset sliding sash will generally make this impossible for interior or exterior storm panels. For sull sash, a close glazing placement will be more achievable.
- Condensation between the glazing layers must be prevented through tight sealing of the interior layer, using weatherstripping or gaskets. For operating sash, a high quality metal compression-type weatherstripping is the best investment in terms of durability and performance.
- The space between layers of glazing must be vented to the outside to equalize inside and outside cavity pressure and dilute any moist air. Vent holes are usually present in the lower rail of a traditional storm. For sull sash, holes should be drilled laterally through stiles.

Impact on Performance
- To address heat loss through air leakage, the choice of weatherstripping is more significant than the choice of single versus double glazing. Air infiltration tests have repeatedly proven that single glazing with proper weatherstripping can meet the requirements of CAN/CSA-A440-M90, the Canadian performance standard for windows.
- Adding a storm to a weatherstripped primary window reduces heat loss through conduction, improves comfort, and helps control condensation. The improvement in insulating value is comparable to that of a standard IG unit, improving the U-value from 1.0 to 0.49 (a smaller number represents an improvement of insulating value).
- The United Kingdom recently passed legislation requiring that all new windows meet a minimum overall U-value standard of at least 3.0 watts/sq.m.K, the equivalent of imperial U-value 0.52. The U-value that can be obtained with single glazing and a traditional storm window satisfies this requirement.

Costs
The low initial expense of these relatively low-tech, low-intervention retrofitting techniques promotes a fast return on the investment.

Long Term Prognosis
- Weatherstripping and seals may require regular inspection and maintenance, but do lend themselves to being maintained or renewed, unlike some of the more high-tech products.
- Generally, only the sull sash inflict irreversible damage on an historic assembly.

Low-Emissivity Coatings
Air leakage aside, it is estimated that two-thirds of the heat transfer through windows is through radiation, with the remaining third lost through conduction and convection. Thus the interest in coatings for glass that reduce the degree to which windows emit radiant heat.

Low-emissivity or low-e glass has a layer of metal oxide that is transparent to short-wave solar energy, but opaque to long-wave infrared energy, allowing most of the sun’s solar spectrum to pass through to the interior, but reflecting heat energy from room-temperature objects and people back into the room. The impact on heat loss through radiation is the equivalent of adding a third layer of glazing.

Within the category of low-e there is a range of selective coatings ranging from “northern” low-e coatings which maximize solar gains and reduce heat loss at night, to low transmission low-e coatings for buildings where cooling loads are significant.
Physical/Visual Impact

- The stick-on low-e films currently available have a distinctly mirrored appearance that would normally be considered inappropriate for traditional buildings with clear glazing.

- While purportedly indistinguishable from clear glass, one study suggests that low-e glass can be differentiated visually from clear glass, and that the reduction in light transmittance may affect the growth of house plants.5

Technical Challenges

Low-Emissivity Coatings Applied to Existing Glazing. The only feasible way of retrofitting low-e technology onto existing glazing is through in situ application of a polyester film. While it may be technically possible to treat historic glass removed from the sash using the sputtered (soft coat) technique, the resulting product is not durable enough to be exposed as single glazing. The more durable “hard coat” process is only possible during the production of new glass and cannot be retrofitted onto old glass.

Single Glazing Replaced with New Low-Emissivity Coated Single Glazing: Replacement “hard coat” Low-E single glass could be incorporated into existing sash, or into a separate storm sash. Ideally, the coated surface should face into a protected cavity between primary and secondary windows. Reportedly impervious to exposure and wear, smudges resulting from putting and painting hard coat glass posed difficulties for a recent Ottawa project.6 This may not compromise the performance of the coating, but can have an aesthetic or cost impact.

Impact on Performance

- With a common stick-on product, emissivity is reduced from 0.84 to 0.35, and U-value reduced from 1.06 to 0.75. For integral coatings, studies show a beneficial effect on U-value ranging from 0.12 to 0.15.7

- Stick-on low-e films are generally designed for the commercial building market, where large expanses of glass require control of solar transmission. For non-commercial applications, the energy saved in heat retention may be offset by reductions in solar gains.7

Costs

- Costs for the stick-on films average $3.75 per square foot installed.

- Coated glazings are two to three times more expensive than comparable uncoated glass. A recent Ottawa project reports $3 per square foot before installation.

Long Term Prognosis

- Stick-on films have warranties ranging from five years to lifetime; average life expectancy for an interior application is 15-20 years.

- For factory-applied coatings, there are no standards or tests to assess long-term durability.

Replacing Single Glazing with IG Units (with or without Low-e)

For a double glazing system, the best thermal performance occurs with a space of about 12mm to 25 mm (1/2 inch to 1 inch) between glazing layers filled with air or with argon gas. Heat loss through convection increases as the gap gets wider, while heat loss through conduction increases in gaps 9mm (3/8 inch) and narrower.

While conduction measured at center-of-glass is decreased in an IG unit, the edges tell another story: the standard aluminum edge spacer conducts heat, reducing the thermal performance of the IG unit and promoting condensation. The “edge effect” applies to a strip about 100 mm (4 inch) wide around the perimeter of the IG unit.10 The smaller the glass area, and the greater the number of individual panes, the more detrimental the effect of the edge on the overall U-value of the window.
As gas-filling and low-e coating technologies advance, the metal edge spacer becomes even more of an Achilles heel. “Warm edge technology” spacers (metal-reinforced butyl rubber or insulated silicone foam), have been shown to improve (decrease) the U-value of the unit by 0.01 to 0.05.11

Physical/Visual Impacts
- Adding IG units to an existing sash will require routing out the rebate at stiles, rails and muntins. Structural integrity may be compromised, particularly in a multiple-pane sash.
- An IG unit in place of single glazing will increase the weight of the sash, requiring adjustment of the counterbalancing mechanism and other hardware in order to permit operation.
- A common accompanying modification is fixing the upper sash in place and replacing the lower sash’s counterweight system with a spring balance, fraught with its own performance and durability limitations.
- Metal edge spacers will be visible at oblique viewing angles. Insulated edge spacers have a more neutral appearance; some versions are available in hundreds of colours at no extra cost for volume orders.12
- The original glass and the reflective qualities or textures it contributes to the facades will be lost. Manufacturers may be convinced to incorporate original architectural glass into an IG unit if the glass in question is relatively uniform and worth the effort, and the units relatively small, for example, bevelled plate glass transoms, but generally perfect float glass is used to ensure the integrity of the unit.

Technical Challenges
- Not all sash can physically accommodate normal 16 mm (5/8 inch) thick IG units. Slimmer IG units have less thermal benefits, unless filled with more costly krypton gas (see later discussion). Otherwise, the benefits of IG units are not realized and the integrity of the sash is compromised for little actual gain.
- The thickness of the sash is not the only constraint. The edge seal takes up 6 to 9 mm (1/4 to 3/8 inch) all around the edge of the IG unit, and must be covered by the rebate in the sash. Newer “super spacers” may be 11 mm (7/16 inch) wide, although modified 5mm (3/16 inch) versions have also been developed (Figure 1). Muntins between two IG units must be wide enough to provide sufficient coverage to edge seals, setting blocks and tolerances, and strong enough to support the considerable weight of the IG unit.
- Even when IG units can physically be accommodated in a multi-light sash, the extent of edge around each unit increases the “edge effect” of increased heat loss through conduction, as well as increased length of vulnerable edge seal. Again, it may not be worthwhile unless insulated spacers are used. Manufacturers generally prefer to have the muntins eliminated or faked in order to have a single IG unit per sash.
- Edge-seal durability is an issue. How ironic that a component used in windows has seals that are degraded by ultraviolet light, moisture and temperature cycling. Traditional ways of holding glass in the sash must be abandoned. As with new window assemblies, it is recommended that pressure differentials between the outside and the glazing cavity be equalized through venting to the exterior; that the cavity be drained; and that the detail include an air seal on the inside of the cavity and a rain deflector on the outside.13 For new windows, this is facilitated with the reverse rebate technique, where the pane is installed from the interior face of the sash, minimizing the surface area of seal on the exterior. This is not possible with existing units, where a wood or metal stop and sealant at the exterior will replace the traditional putty line (Figure 2).
- The risk of point loading is greater in retrofit applications, where sash are more likely to be somewhat warped or out of square, than in controlled manufacturing processes using new materials.

Impact on Performance
- Thermal Performance:14

| IG unit with 6mm (1/4 inch) air space: U-value is 0.67 |
| IG unit with 12mm (1/2 inch) space: U-value is 0.49 |
| IG unit with low-e: U-value is 0.28 |
The low-e component will reduce solar transmission, which may be disadvantageous where passive solar heat gain is desirable.

- UV transmission can be reduced by 10 percent or more.

- For the period that the edge seal is intact, the change from non-sealed to sealed units eliminates condensation between the glazing layers, and reduces the number of glass faces requiring cleaning.

- Condensation resistance is improved. For example, with an outside temperature of -18 Celsius, single glazing can support 13 percent relative humidity while double glazing can support 41 percent relative humidity.

- IG units have no impact on heat loss through air leakage.

Cost

- IG units are three times more expensive per square foot than single thickness glass.

- IG units with low-e coatings are 35 percent more expensive than clear IG units.
Long Term Prognosis
- The vulnerability of the joint between the IG unit and the sash can result in increased maintenance costs and a shortened service life for the unit.\(^{15}\)
- A five-year warranty is the industry standard for IG units. If the unit fails within that period, the manufacturer will supply a new unit but may not cover the costs of installation.
- The damage to historic fabric is irreversible.

Replacing Single Glazing with Gas-Filled, Low-e Coated IG Units
While dead air between layers of glazing is a good insulator, inert gases such as argon and krypton are less conductive and also hamper convection, reducing heat transfer between the glazing layers.\(^{16}\)

For a higher cost, krypton gas yields better thermal performance and a slimmer IG unit: the optimum space between the glazing layers is 6mm (\(\frac{1}{4}\) inch).\(^{17}\)

Physical/Visual Impact & Technical Challenges
- The gases are invisible.
- Slimmer krypton-filled IG units can be accommodated in slimmer sash.
- See above under "Replacing Single Glazing with IG Units."

Impact on Performance\(^{18}\)
- Compared to a standard IG unit, 15 percent to 20 percent increases in insulating value at center-of-glass may be achieved with krypton and argon gas fills, low-e coatings and multiple glazings.

- Warm edge spacers have been shown to improve U-value by 0.01 to 0.05; argon fill, by 0.05; low-e coatings, by 0.13.

- 90 percent argon fill in a standard sealed unit yields only a 5 percent improvement in the insulating value at the center of the glass, as compared with a non-gas-filled unit.

- Data suggests some sound attenuation may be achieved with gas filled IG units.

Costs
- Krypton gas fill costs $1.00 more per square foot than argon.\(^{19}\)

Long Term Prognosis
- Whether gas filled IG units sustain their initial performance values, and whether they are as full of gas as they should be, are factors currently not regulated by standards or tests.

- The National Research Council of Canada - Institute for Research in Construction has developed a technique for measuring argon concentration in IG units. In a round of testing, it was found that, despite most manufacturers’ claims of 95 percent gas concentration in new units, actual argon concentrations ranged from 99 percent to 31 percent. Accelerated aging tests suggest average gas losses of 0 percent to 10 percent over five years, as well as some 100 percent losses.\(^{20}\)

The Last Word
- The energy effects of an improved U-factor for the windows are not dramatic if windows are a small percentage of building envelope.

- A National Capital Commission study based on a range of window retrofit and replacement projects found that restoration, weatherstripping, and adding a storm and screen is 24 percent cheaper than replacement with new argon-filled low-e IG windows, and that it would be 25 years before costs equalized.\(^{21}\)

- While great improvements have been made in streamlining IG units without compromising performance, retrofitting existing historic sash with IG units should be resisted if the installation detail cannot support the maximum performance and service life of the new IG unit.
Notes

1 The glut of performance data available, variously reported in R, RSI, U metric, U imperial, ER and NFRC ratings, is often difficult to compare. In this paper, insulating value will be reported in U-value (imperial), which represents rate of thermal losses in Btu/hr-sq. ft. -degree Farenheit.

2 Edgetech Newsletter 5, no. 2.


5 Virginia Salares and Peter Russell, Low-e Windows: Lighting Considerations (Ottawa: Canada Mortgage and Housing Corporation, 1995).


7 Edgetech Newsletter 6, no. 2.


11 Edgetech Newsletter 6, no. 2.


13 Edgetech Newsletter 2, no. 2.


18 Ibid, 60.


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WINDOW REHABILITATION GUIDE FOR HISTORIC BUILDINGS IV-43
Let There Be Daylight

Ross McCluney, Ph.D.
Principal Research Scientist
Florida Solar Energy Center
Cocoa, Florida

Introduction and Background

Much of our country's rich heritage is represented in its historic buildings, many of which are worth preserving. Apart from any historic quality a building might have, if it is worth preserving, it is worth keeping in use as well. Keeping the occupants of the building comfortable and happy, without incurring exorbitant energy bills is an obvious goal of any preservation or restoration project. As to the energy saving goal, a friend of mine once said, "If you want to save energy, turn off the gas and electricity and send the people home." Buildings are made for people, and hopefully for their comfort and productivity while inside. What we really want are buildings that are comfortable and enjoyable in which to live, play, and work. Conserving energy along the way is a laudable goal, but not the primary one.

Revolution in window manufacturing

The good news is that window manufacturers are completing a technological revolution that has produced an expanded new supply of wonderful, delightful windows, in nearly any style and type, many of which also are very energy efficient and user-friendly, to borrow a phase from the computer world. What does "user-friendly" mean in this context? Window characteristics of interest and importance to users include:

- Visible transmittance, how much light the window lets in and how easy it is to see out
- Color of the glass, as viewed from the inside and outside
- Color-rendering quality of the transmitted daylight, ability to render interior colors properly
- U-factor, ability to block conductive heat flows through the fenestration system
- Solar heat gain coefficient, ability to pass or reject solar radiant heat gain
- Condensation resistance, resistance to interior condensation on cold winter nights and exterior condensation on hot humid days when the interior is cooler than the exterior
- Durability, permanence of the above properties over time

"User-friendly" means that each of the above characteristics satisfies occupant needs. It should be obvious that different purchasers, building types, climates, and window orientations will produce differences in needs for the above properties. A high solar gain window to provide passive solar heat gain for northern Maine would be a disaster for the hot, humid climate of southern Florida.

Window selection

Increased insulation to prevent heat escape on long, cold winter nights in northern climates might be a waste of money or even a detriment
Choosing the right window for one's taste, climate, and building type has not been made easier by manufacturers increasing their window selections to better meet the varying needs of different buyers. Understanding all aspects of fenestration performance, including the physics of fenestration energy transfers, is important for fenestration industry professionals. Having this understanding should help them better to understand the problems and opportunities, and make them better able to advise clients about choosing the right fenestration system for their needs. Requiring this detailed technical knowledge of architects and other product specifiers, or of consumers, could be overkill.

Fortunately, a new organization has been established that should make window selection easier and manufacturers' performance claims more reliable. It is the National Fenestration Rating Council (NFRC). The Council has standards in existence or under development on the optical properties, insulating ability, solar gain property, condensation resistance, and long-term energy performance of fenestration systems.

A new book was published last year offering simple information and guidance in the selection of fenestration systems for residential applications. Packed with information, data, and illustrations, this new book is a must read for anyone involved in window selection for residential buildings. Much of the information it offers is applicable to nonresidential ones as well. A more specialized and more detailed technical publication on the solar heat gain aspects of windows is available from the Florida Solar Energy Center. For more detailed information on colorimetry and other aspects of radiometry and photometry, a textbook on the subject is available.

**Daylighting and productivity**

There is more to windows and their ability to illuminate interiors than can be included in a list of window characteristics. A daylighting system includes not only the windows as components but also their size and placement with respect to occupancy areas inside, and the paths followed by the sun outdoors. A daylighting system is part of the architecture of a building and has impacts not only on the short-term comfort of the occupants and the visual appearance of the space but also on the longer-term comfort and productivity of the occupants.

Productivity is especially tied to these factors in non-residential buildings, and window impacts on productivity can far exceed the energy impacts from an economic or business management standpoint. In a typical office operation, the monthly energy bill is only a few percent of the monthly personnel bill. Salaries generally far exceed energy costs.

If you do something to a building to reduce the energy bill by half, for example, you might in the process reduce worker productivity by 5 percent. The monetary value of the 5 percent loss of productivity in many buildings is greater than the whole energy bill, much less half of it. On the other hand, suppose you find a way not only to save half the energy bill but increase worker productivity by 5 percent or 10 percent! The monetary benefits of the productivity increases far outweigh those of the energy savings. It is possible, with proper building design and window placement, sizing, and selection, to accomplish both goals.

**Recapturing the art of daylighting design**

With existing buildings one does not have the luxury of new design, of being able to stretch and form the building, and orient it properly for best daylighting and energy performance. There is another way to look at it though. The art of good daylighting design was a necessity before the widespread use of electric lighting. This art has been lost to many young architects today. Finding historic old buildings with good design for daylighting, and restoring them to their former excellence, will benefit not only the culture of America, but will preserve examples of good daylighting designs and strategies. The challenge is to do this while improving occupant comfort and building energy performance in the process, using modern technology to retain the best of the past while overcoming energy-wasting and comfort-reducing practices forced by previously limited materials and knowledge.
**Needs of historic buildings**

Historic buildings clearly have special needs that must be considered in window selection. In nearly every case the building and its windows already exist. Exceptions include jobs to restore badly damaged buildings or portions of buildings, or redoing a previous restoration or rebuilding that was not true to the historic character of the original. In all such cases, the new window should look as nearly identical to the original or previous historic window as possible, or at least must have a design and appearance appropriate for the historic period and character of the building.

In the past this produced serious constraints on the energy efficiency of the replacement window. In many cases it also meant that the size of the window could not be changed and the new window had to be an exact duplicate of the old one, meaning hand fabrication by special craftsmen was often required.

Many large national window manufacturers now have the capability to make new windows with the exact appearance of historic old windows, but with the hidden interior cores of the framing elements of new materials, providing greater structural strength, insulating ability, and durability. The glazings of these new windows in many cases can look like the old ones, but have greatly improved energy performance characteristics. Both of these abilities can be provided to custom designs that match the appearances of old windows. An energy efficient window is no longer just a double pane window with an insulated frame. There is more to it than that. To help understand modern energy efficient windows, some additional background information should be helpful.

**Slightly Technical Background**

Windows, skylights, clerestories, sliding glass doors, sloped roof glazings, and glazed doors all fall into a general category called fenestration. The fenestration system, including any shading devices, attached to it, as well as its frame and other opaque elements, limits the admission of solar radiation and daylight. The limiting action includes the effects of the edges of the aperture and other opaque elements of the system in blocking solar radiation and daylight. It also includes the processes of transmission, absorption, and reflection by the glazings and other elements. Several physical mechanisms are involved in these actions.

**Energy flows**

Energy flows through windows have two forms. First is solar radiant heat gain, and second is the conduction of interior heat to the outside in the winter and outside heat into the interior in summer. These flows are illustrated in Figure 1.

The solar gain is composed of two parts. First is the directly transmitted solar radiation and second is that absorbed by the glass and opaque elements of the window and then conducted, convected, and radiated to the interior. For multiple pane or insulated windows, the conduction heat transfer actually includes some convection and radiation components, heat radiated and convected between the panes, heat convected and radiated between the interior and the inner light, and heat radiated and convected between the outside and the outer light.

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Figure 1. Illustration of energy flows through a window.
U-factor
The insulating ability of a window, its ability to block the conduction transfers, is characterized by the U-factor, a coefficient that expresses the heat transfer as watts of heat flow per unit area of the window and per degree of temperature difference between the inside and outside. For windows in cold climates, where the temperature differentials, the delta T's, are large for much of the year, having a low U-factor is very important. For such climates, having high solar gain too can also be very helpful in warming the interior when the sun is out on cold winter days.

In NFRC ratings, there is a distinction between the U-factor of the center of a glazing system, the edge of the glass (which has a generally higher U-factor), and the frame. There is also an overall U-factor for the whole window assembly. The overall U-factor is the key value for determining energy efficiency, since all portions of the window conduct heat, not just the glass.

Providing windows with a terrific center-of-glass U-factor does not necessarily lead to good energy performance. The good center-of-glass glass performance can be sabotaged by conduction “short-circuits” through uninsulated frames, or through the metal spacers holding apart panes of a multiple pane glazing system.

The U-factor of a window can be lowered by the obvious means of using insulating materials in their frames and using multiple panes to create one or more insulating air spaces between the panes. Less obvious means include the introduction of better-insulating gases into the air spaces and the application of special coatings to glass surfaces between the panes. Argon and krypton are two commonly used insulating gases that can lower U-factors of double pane glazing units as much as 20 to 40 percent, depending upon the glass spacing. Low-emittance coatings, which can lower U-factors by 10 to 30 percent, are described subsequently.

Solar gain
The solar heat rejection ability of a window, its ability to exclude the heat of solar radiation, is characterized by the solar heat gain coefficient (SHGC), which gives the fraction of incident solar radiation that enters the building as heat gain, ending up as a load on the air cooling system. The SHGC includes both the directly transmitted component and the absorbed and re-emitted component of solar gain.

In hot climates it is generally more important to have a low SHGC than to insulate the window, since in many such climates the temperature difference between inside and outside is seldom very great or for long time periods. However, the best glass coatings for solar gain rejection and daylight admission are too soft to be placed on exposed glass surfaces; they must be protected inside a laminated glass pane or between the panes of a two-pane system. So it is not irrational to want insulated glazing systems with uninsulated frames in hot and mild climates.

Like the U-factor, SHGC has both center-of-glass and frame components. With solar gain, the edge-of-glass value is the same as the center one. Again, it is the overall window SHGC that should be considered in determining window energy efficiency.

Things are seldom quite as simple as they seem at first. Window energy performance is no exception. For example, modern commercial buildings in cold northern locations are generally designed to minimize exposure to the cold outdoors. These buildings have a high volume-to-surface area ratio and are what is often called internal load dominated, meaning that heat from the electric lights, building equipment (computers, air handlers, copy machines, etc.), and people dominates in keeping the building comfortable. (Each person, on the average, emits about as much heat as a 100 watt light bulb.)

Heat loss through the windows is relatively minor by comparison. Some internal load dominated buildings generate so much heat inside from these sources that a separate heating system is not needed, even in a city as far north as Toronto. The Ontario Hydro headquarters building in Toronto, for example, was designed without a heating plant of its own. Heat from the electric lights and equipment was stored in huge insulated water tanks in the basement during the day, and this heat was used to heat up the building before the start of the work day early the next morning. If this ever proved to be
inadequate, steam could be purchased from an
adjacent building to supplement the heat from the
stored water.

In such cases, any added heat from solar
radiation causes the air conditioning to have to be
turned on, even in mid-winter! In consequence,
it is not uncommon to see office buildings in cold
northern locations with single-pane, tinted, solar
gain rejecting windows. Such windows should
not be used on northern residences, with their
generally lower volume-to-surface area ratios
and much lower internal heat generators.

Infiltration
Infiltration is another useful property of windows,
though for modern windows the infiltration rate is
generally so low as to be inconsequential for
energy or human factors purposes. Excessive
infiltration in older windows can be one cause of
the feeling of “draftiness.” Modern windows, if
they are installed properly, have very low
infiltration coefficients and do not produce
occupant discomfort due to high infiltration rates.

The other cause of feelings of draftiness is the
use of uninsulated single pane glass. On really
cold days and nights the glass is cold enough that
it cools the indoor air immediately adjacent, and
the cold air, being heavier, descends from the
window into the room. Indoor air currents can
waft these cool air currents over the occupants,
producing localized discomfort.

Condensation
Perhaps more serious, especially for northern
locations, is condensation. Condensation resis­
tance is the ability of a window to prevent
interior surfaces in contact with the warm humid
air of a building’s interior from dropping below
the dew point temperature, the temperature
below which moisture condenses on surfaces.

Condensation is unsightly, a sign of a poorly
designed and/or manufactured window, and can
produce premature degradation of window
components, the growth of mold or mildew, and
the rotting or rusting of window frames. In
extreme cases, frost can actually form on the
interior surface of the window. The cure for
condensation is to lower the U-factors of the
glass, the edge of the glass, and the framing

elements. Having these areas properly insulated
prevents interior heat adjacent to the window
from escaping, which would lower interior
window surface temperatures and promote
condensation. Properly insulated windows have
what are called “warm” interior surfaces during
cold winter periods.

Although condensation resistance is of most
interest for buildings in cold climates, it can also
be a problem for single pane windows on air-
conditioned buildings in hot, humid climates,
producing condensation on the outside of the
window. Insulating the window is an effective
cure for this problem, whether in cold or hot
climates.

Outside condensation can also occur on rare cool
but damp, still air nights with very well insulated
windows. The insulation of the outer window
surfaces from the warm interior air can result in
outside surface temperatures dropping below the
dew point, producing condensation on the
outside. This is usually an infrequent and
relatively inconsequential occurrence.

Condensation can occur between the panes of
multiple-glazed windows. Not only does this
degrade the view, but it can become a nearly
permanent feature of the window, since the
moisture may have no easy way to exit the dead
air space between the panes. Factory-sealed
insulated glazing units (IGUs) are the best cure
for this condition, but the factory doing the
sealing must do it correctly.

The National Fenestration Rating Council is
working to develop a condensation resistance
rating that will appear on the NFRC window
energy performance label. Until this becomes
available, low U-factor can be used as an
indicator of condensation resistance.

Visible transmittance
Visible transmittance, the fraction of incident
light that is transmitted inside, is probably the
most important characteristic of a window.
Windows are made to see out of and to admit
daylight. Both of these abilities depend upon a
relatively high visible transmittance, whose
symbol is $T_v$. Single pane clear glass has a $T_v$
of about 0.92 or 92 percent. Double pane glazings
have visible transmittances that are only slightly lower than this value.

Glass that is tinted for solar gain control or glare prevention can exhibit $T_v$ values as low as 0.08, or 8 percent, but the resulting windows are relatively difficult to see out of, the interiors are dimly lit by daylight, and electric lighting is required during daytime hours. Visible transmittances should ideally be kept above about 40 percent, with higher values being required for maximum solar heat gain in cold climates.

It costs more purchased energy to operate electric lights, and remove the heat they produce, than to remove the much smaller quantity of heat gain from a good daylighting system providing the same illumination level. If a spectrally selective glazing system, described in the next section, is used to block the infrared portion of the solar spectrum without lowering the visible light transmittance, the solar radiant heat gain is less without much loss of visible transmittance.

Special Coatings

As mentioned previously, the addition of special coatings on glass surfaces and the addition of tints to the glass itself can improve glazing energy performance. To understand how these coatings work, take a look at Figure 2. This figure shows the electromagnetic spectrum ranging from the ultraviolet (UV) region below 360 nm through the visible (VIS), across the infrared (IR) part of the solar spectrum above about 700 nm, and out into what is called the far infrared spectrum. As can be seen in this figure, the solar radiation incident upon windows covers the range from about 350 nanometers ($350 \times 10^{-9}$ m) to about 3,000 nm, which is the same as 3.0 micrometers, or 3.0 m.

The emission spectrum from room temperature objects, by contrast, ranges from 3.0 m to over 40 m. This separation of the infrared emission spectrum from the spectrum of solar radiation is what makes possible the action of special coatings for cold climates called low-emittance or low-e coatings. These coatings are the first example of a class of coatings called spectrally selective, meaning that one or more of their optical properties is different in one part of the spectrum than it is in another. This is illustrated in Figure 3, showing the reflectance spectrum of an idealized low-e coating.

One can see in Figure 3 that the coating’s reflectance is low over the whole solar spectrum, resulting in a high transmittance over this region.

Low-e coated glass is designed to admit as much solar radiation as possible, to heat building interiors on cold winter days. The reflectance is very high, however, over the spectrum of far infrared radiation emitted by room temperature objects, such as the inner pane of a multiple pane system. What this means is that radiation emitted by the inner pane across the air space between the two glazings can be reflected by a low-e coating on the inside of the outer pane.

The combination of high transmittance to solar radiation and high reflectance to long-wavelength infrared radiation from the inside trying to get out effectively traps the solar radiation inside. This reduces the amount of heat needed to warm the building. The low-e coating is most effective at keeping heat inside during night time hours when outside temperatures are the coldest.

The ability of a high performance window such as this to admit more solar heat in the daytime than is lost by conduction through the window at
A good reflector in one part of the spectrum can be a poor reflector and a good absorber in another part.

Figure 3. Plots of the spectra shown in Figure 2, but with the reflectance spectrum of an idealized low-emittance coating added.

Figure 4. The same plot as Figure 2, but with the reflectance modified to exclude near infrared radiation contained in the solar spectrum while maintaining high transmittance over the visible portion.

night and during the day makes it as good an energy performer as an opaque insulated wall. When high performance windows such as this are used, the old adage about windows being “holes in the insulation,” is no longer true, and the designer gains a new freedom, a freedom to make windows as large as needed or desired for a variety of reasons, without much, or any, energy penalty.

All this is well and good, you may say, for cold northern residential applications. But what about internal load dominated commercial buildings or buildings in hot climates? The heat-trapping ability of what I like to call “conventional” low-e windows would be a disaster for most of these situations. An answer can be found in Figure 4. In this figure the increase in spectral reflectance of the coating when going from the incoming solar spectrum part of Figure 3 is moved to the left, closer to the edge of the visible portion of the spectrum. The result is what optical physicists like to call a “heat mirror.” It is also called a “band-pass filter.”

The first term refers to the ability of the coating to reflect much of the infrared heat energy contained in the solar spectrum back outside, before it can enter the building. This makes it an effective heat mirror, reflecting the near infrared portion of the solar spectrum back outside while letting the desirable visible light in.

The “band-pass” nature of the coating is illustrated in Figure 5, which shows the idealized transmittance spectra of both a conventional low-e coating and a so-called “low-e-squared” or special spectrally selective coating intended for hot climate applications. Actually both coatings are spectrally selective, but they are spectrally selective in different parts of the spectrum.

It is important to note that just under 50 percent of the radiation in the whole solar spectrum lies in the visible portion. Thus, the idealized “low-e-squared” coating has the potential for reducing the solar heat gain by a factor of 2, to 50 percent of the value for clear glass, while maintaining a high visible transmittance near 90 percent. Modest reductions in the visible transmittance can further reduce solar gain, but with only modest loss of useful daylight.

Light-to-solar gain ratio
I have introduced a special figure of merit for spectrally selective window glazing systems. It is called the light-to-solar gain ratio, or $LSG$. It is defined to be the ratio of the visible transmittance, $T_v$, to the solar
Uncoated aluminum (and anodized aluminum) is a popular framing material and its high thermal conductance can be overcome with what are called “thermal breaks.” These are sections of low thermal conductance material placed in the aluminum frame in such a way as to block the thermal “short-circuits” these frames used to suffer. Other materials are available to provide differing appearances with good energy performance. As mentioned in the previous section, wonderful new glazing systems are now available that look much like their old single-pane clear parents, but which now have marvelous energy conservation properties not available previously.

The available shapes and geometries of windows likewise have expanded. There are curved windows, projecting and casement windows, skylights and roof windows, and greenhouse (garden) windows. Windows with simulated divided lights deserve special mention. It is generally expensive to make windows with numerous divided lights, meaning windows with a variety of separate panes, separated by opaque dividers going from outdoors to indoors and have each of these lights sealed insulated glazing units. A popular alternative is to make one large IGU and to put simulated dividers on both the outside and inside of the IGU. This compromise provides the look of divided light windows but the energy and comfort performance of the best IGUs using insulating gases and low-e coatings.

### Putting It All Together — Meeting Human Needs with Energy Efficiency

#### Visual appearance

Several large national window manufacturers have modern computer-aided custom design capabilities. With a variety of framing materials from which to choose, and freedom to make insulated glazing units of nearly any size and shape, it should be possible to mimic, if not duplicate, the appearance of any old window in an historic building. With the vast array of new glazing systems available, it should be possible to maintain good view and daylighting performance while maintaining good solar heat gain (or reducing it where warranted) and high insulation.

### New High Performance Windows

As mentioned previously, a wonderful variety of window types, styles, and performances is available to the designer today. Gone are the requirements to have only wood in residential windows and steel in commercial and institutional ones. Window frames are now being made of durable vinyl, vinyl-coated wood, and even vinyl-coated aluminum.

Figure 5. Plots of the spectra shown in Figure 2, but with the transmittance spectra of low-e and specially spectrally selective coatings added.
against conduction heat gains or losses. It might even be possible to manufacture, on special order, a pane of clear glass with the few small bubbles and surface irregularities characteristic of the cast and blown glass of old, and to put one of these panes into an insulated glazing unit along with a modern clear pane, thereby maintaining the historic old appearance while insuring good insulating ability.

**Daylighting and Productivity**

With high $T_e$ glazing systems, the daylight illumination abilities of old buildings with large windows for good daylighting performance can be maintained, with greatly improved energy performance as well. The productivity gains that are connected with daylight illumination and good views of the outdoors are an added benefit that has important economic ramifications.

**Visual Comfort**

With modern windows in historic buildings, and with interior and exterior shading elements in keeping with the styles of the period, it should be possible to avoid glare and maintain good visual comfort.

**Thermal Comfort**

With insulated windows and frames and good sealing technologies, the draftiness and other thermal discomforts associated with old windows can now be avoided. With “warm” interior panes, so-called radiant temperatures near the windows can be maintained at comfortable levels.

**Energy**

Modern energy efficient windows offer lowered monthly energy costs. The larger the window areas, the greater the lowered costs. One need not replace historic windows with smaller ones to save energy costs.

**Electric demand**

Non-residential buildings in some electric utility service territories have to pay what are called demand charges in addition to their monthly energy bills. These extra charges are based on the peak rate of electricity usage demanded by the building during the course of a month. Any strategy for reducing peak loading on the building’s electric heating and cooling systems will be reflected in lowered demand charges.

Well-designed modern windows can reduce demand charges in summer by reducing solar gains, in winter by reducing heat losses, and all year long by reducing daytime electric lighting usage during peak energy use periods.

**Laminated glass**

In areas where vandalism is a problem, or damage from hurricanes or tornados is a fear, very strong laminated glass, or panes of glass and plastic sheets laminated together can be used. One company offers laminated glass with spectrally selective coatings sandwiched in the middle. Others offer a laminated pane as the outer one of a double pane IGU.

**Concluding Remarks**

Modern window materials, designs, and manufacturing techniques make it possible to achieve human comfort and productivity performance, and good energy performance, while maintaining the look and feel of old windows in historic buildings. The designer or retrofit builder has only to search the window company catalogues, or talk to knowledgeable custom window manufacturers, to come up with replacement windows that can achieve these goals.

The National Fenestration Research Council has come a long way toward insuring that the energy and visible transmittance performance claims of these manufacturers can be trusted and counted on. Look for the NFRC window energy label when specifying windows. If the window is a custom one, it may not have an NFRC label and may not be certified by the NFRC. However, you can insist that the window be rated according to NFRC procedures. With this rating, you can be confident that the window will meet energy efficiency expectations and will exhibit other thermal and visual characteristics promoting human comfort and productivity.
Notes

1 National Fenestration Rating Council, 1300 Spring Street, Suite 120, Silver Spring, Maryland 20910.
"Light, God's eldest daughter, is a principal beauty in a building."

*Thomas Fuller (1608-61)*

Light is damaging to organic materials. Since windows admit light, protection of organic historic artifacts is aided by elimination of windows.

Historic interiors can best be appreciated using historic lighting sources; and windows are often the most interesting architectural elements of historic facades. Therefore windows must be preserved.

Acceptable strategies for resolution of the conflicting demands of historic buildings and the collections they expose to daylight are the subjects of this paper.

**Collections Conservation**

Damage to collections from light is a severe problem. Any organic material exposed to light deteriorates. Most obvious is fading of fabric dyes and wood finishes, but more serious is destruction, at the molecular level, of historic materials such as textiles and wood. This deterioration is cumulative and nonreversible. All wavelengths of the electromagnetic spectrum — short (ultraviolet or UV), medium (visible), and long (infrared) — contain damaging energy. For a given intensity, shorter wavelengths (UV and blue) are more damaging than longer wavelengths (red and infrared). Deterioration is cumulative: exposure to 10 footcandles for one year is equivalent to one footcandle for ten years. Damage is irreversible: any object exposed to light is being permanently damaged.

The only fully-effective strategy for dealing with this problem is permanent storage in the dark. For historic artifacts displayed in an historic setting, reduction of light to the lowest practical level and exposure for the shortest possible time are practical, partial alternatives.

This is not a recent problem; curators and housekeepers have long been aware of the ill effects of light exposure. Traditional solutions include use of interior and exterior blinds to keep rooms both cool and dark, and the use of heavy drapes to block light. Historic interiors equipped with blinds and drapes are appropriately protected with these devices, with the understanding that the blinds and drapes are sacrificial: light will destroy them. Blinds and drapes with intrinsic historic or architectural interest should be stored in the dark and modern substitutes should be used in their place.

To reduce the duration of light exposure, curators often rotate collections, exposing individual objects for relatively brief periods. While this strategy is demonstratively effective for individual objects, it is ultimately ineffective for the collection as a whole, since it does nothing to reduce total damage by minimizing the hours that blinds and drapes are open.

Some collections curators might prefer to deal with the problem of sunlight by walling over windows, a highly effective solution. Since this
extreme approach is rarely acceptable for any
type of windows in historic buildings, a popular alterna­
tive is the use of transparent, UV-filtering film,
which is applied to window glass. Advantages
of this film include low cost and full-time protec­
tion. Disadvantages include gradually declining
effectiveness and difficulty of replacement.

Building Conservation
Buildings are affected by light in the same way
as collections. Traditional methods of reducing
damage include the use of inorganic materials
such as brick and stone and the use of paints to
protect organic materials. A higher tolerance for
light-induced exterior damage and a willingness
to replace exterior coatings make exterior
damage less of a perceived problem. Interior
damage, especially to finishes, is similar to that
suffered by collections, but building conservators
find walling off windows from the interior
unacceptable for reasons of aesthetics, mainte­
nance, and conservation. First, the windows are
significant architectural elements and their
permanent covering has negative effects on the
aesthetics of both the exterior and interior.
Second, access to the interior of windows is
necessary for routine maintenance. Third,
windows walled off from the interior are apt to
suffer condensation damage which is difficult to
spot and impossible to correct.

On the other hand, the use of blinds and drapes
is often acceptable to building conservators,
because of the historic precedent for these
materials. Although most conservators are
conscious of damage to drapes, sacrificing them
in the interest of saving other fabric, damage to
wooden blinds is not usually given much thought
and attention. The principle difficulty encoun­
tered with the use of drapes and blinds is the
discipline required for their full effectiveness. In
order to work they must be closed, usually a
manual process dependent on well-trained
docents and vigilant curators. Few organizations
can guarantee both 100 percent of the time.
And even the most zealous docent is apt to open
blinds once in the morning and close them once
in the evening, even though the effected room
may be unoccupied 90 percent of the time.

Building conservators object to films because
they are usually applied directly to historic glass.
They are difficult to remove and since they must
be replaced from time to time, either because the
adhesive fails (organic, exposed to light) or
because the UV-filtering capability of the film
degraded, some damage to the glass and/or sash
can be expected each time the film is renewed.
A second drawback is that films are generally
chosen because they are “clear”; they block UV
but transmit 100 percent of visible light. Al­
though constantly working, they are much less
effective than closed drapes and blinds because
of this visible light transmittance.

Ideal Solutions
Any solution to the sometimes conflicting require­
ments of collections curators and building conser­
vators should satisfy the following criteria:

• Blockage of 100 percent of UV light
• Choice of transparencies: some locations
  might benefit from more or less visible light
• Control of infrared light
• Full-time effectiveness
• Minimum impact on interior and exterior
  appearance
• Easy removal
• High durability
• Ease of acquisition (availability and cost)

No single, simple installation or material can
satisfy all of the above. An excellent program
might combine operational practices such as
careful, constant attention to closing blinds and
drapes, with building modifications such as the
replacement of historically significant blinds and
derapes with sacrificial copies, and the installation
of easily demountable, innocuous, transparent or
semi-transparent UV filters.

Design of demountable light filters is a key issue
since any filter other than one applied directly to
the glass will change the appearance of the
window. Interior storm panels glazed with
acrylic (or glass with a UV film applied) have
often been used at the cost of some minor effect
on the interior appearance of the window.
Experience has shown that in cold climates,
condensation between the prime and storm sash
can lead to deterioration of both sash and frame
members, especially sills. Since the exterior,
historic sash usually allow a good deal of air movement, condensation occurs on the inner, modern sash. This condensate then runs down to the window sills and encourages rot. Of course, the prime sash are exposed to the exterior and continue to deteriorate from normal weathering.

Exterior storm windows have a visual impact on the building (minimized, of course, if they are carefully designed to be unobtrusive). They do, however, protect historic sash from normal weathering. Since historic sash tend to be delicate, the sacrifice of historic appearance may be worthwhile. If exterior storm sash are acceptable aesthetically, they nicely meet the criteria of removability and provide the benefits of physical protection, reduction of dust infiltration, interior temperature stabilization, and some minor energy conservation.

If exterior storm sash are acceptable, the question of appropriate glazing remains. Sometimes the use of polycarbonates is recommended due to resistance to breakage and blockage of UV. Although initially acceptable, plastics soon become visually offensive due to weathering (scratching) and yellowing (organic decay from exposure to light). Glass is the preferred choice since it remains clear and is scratch-resistant. However, glass that blocks infrared radiation is deficient in its ability to block UV. A suggested practice is to hang acrylic sheet plastic on the inside of an exterior storm sash glazed with glass. This combines the appearance and durability of glass with the UV reflectance of plastic. The plastic is protected from scratching and can be easily replaced, with no impact on the historic fabric, when it discolors. A further advantage to acrylic is that it is available in a range of tints that screen from 10 percent to 90 percent of visible light. While the darker tints offer the maximum protection from UV radiation, they are not recommended for historic structures, since they can obscure the original windows and alter the historic character of the building.

The illustration shows some of the practical considerations and mounting details found to work on specific buildings. Details may have to be adjusted for each case. Costs of two examples are tabulated below.

### Summary
Protection from light requires good operational practices together with light-filtering devices. Practical light filters that will reduce both UV and visible radiation can be constructed from traditional storm sash, supplemented with piggy-back acrylic sheets.

### Cost Table

<table>
<thead>
<tr>
<th></th>
<th>Stone-Tolan</th>
<th>Campbell-Whittlesey</th>
<th>Notes</th>
</tr>
</thead>
<tbody>
<tr>
<td>sash, glazed</td>
<td>$ 120</td>
<td>$ 72</td>
<td>all sash 5/4 clear pane</td>
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<tr>
<td>sash</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>glass</td>
<td></td>
<td>$ 100</td>
<td>tempered glass used for CW</td>
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<tr>
<td>glazing</td>
<td></td>
<td>$ 16</td>
<td></td>
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<td>$ 50</td>
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<td>$ 60</td>
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<td>$ 60</td>
<td>mounting methods varied</td>
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<td>$ 94</td>
<td>15% and 10%, compounded</td>
</tr>
<tr>
<td>cost per window</td>
<td>$ 547</td>
<td>$ 452</td>
<td></td>
</tr>
</tbody>
</table>
Notes

This phenomenon is well documented in the technical literature. Easily accessible references include:


Degradation of the UV-filtering capability of the film is an insidious problem because the film gives a false sense of security. The film looks the same whether or not it is effectively blocking UV radiation or not. Actual effectiveness of the film can only be determined by regular testing with equipment to which many house museums do not have access.

The infrared portion of the spectrum consists primarily of heat energy. The issues of heat absorption, transmission, and reflectance of heat have a large impact on the climate control system and are more locale-specific than UV and visible light. There is a bewildering array of options in the selection of glass to help tune the infrared absorption characteristics of a building. That issue—choice of glass to optimize use of infrared light—is beyond the scope of this paper.


Acrylic sheet plastic is the generic name for a number of products such as “Plexiglass,” a Rohm & Hass trademark, or “Acrylite,” a Cyro Industries trademark. Various degrees of UV and visible light transmittance are available.

Caution! This is not a recommendation for storm panels over leaded glass. Experience has shown that the “greenhouse effect” causes temperature extremes that are damaging to leaded glass.

Why not major energy conservation? Historic buildings should probably not be heated much in winter nor cooled much in summer. Both buildings and collections seem not to be harmed by slow seasonal variations in temperature but can be severely damaged by artificial (rapid) heating and cooling, and subsequent changes in relative humidity. The opportunity for major energy savings just does not exist if interior building temperatures are allowed to fluctuate with the seasons as they did historically. Storm panels do help to flatten out daily temperature fluctuations and so are beneficial independent of any artificial heating or cooling.

Polycarbonate sheet plastic is the generic name for products variously known as “Lexan,” a General Electric Company trademark, or “Cyrolon,” a Cyro Industries trademark, or others.

Choice of glass is not dealt with here. Insulating, reflective, and “low-e” all have pitfalls. Clear glass is usually the safest choice unless some special goal is sought.

This combination, a glass storm sash plus a plastic interior panel, was suggested to the Landmark Society of Western New York during a consultation in 1991 by Mr. Paul Himmelstein of Appelbaum & Himmelstein, Conservators of Works of Art, 444 Central Park West, New York, New York, 10025.

The Stone-Tolan House is a circa 1800 restored Federal style farmhouse owned and operated by the Landmark Society of Western New York as a house museum. Prices quoted were provided by Mr. Fred Steele of Fred R. Steele, Inc., 3035 Ridgeway Avenue, Rochester, New York, 14606. Work consisted of installation of 22 wooden storm windows, half of which included acrylic piggy-back UV protection. Openings were very irregular and each window was custom-built and custom-fitted in the field. The shallow rebate required that each sash stile be plowed out on the back to fit into the opening. Storm sash priced in this report were about one-over-one, about 33 inches wide by 60 inches high. Work was done in 1994.

The Campbell-Whittlesey House is a circa 1840 restored Greek Revival style home owned and operated by the Landmark Society of Western New York as a house museum. Prices quoted were provided by Mr. Jerry Klafehn, Kend General Contractors, 1 Mt. Hope Avenue, Rochester, New York 14620. Work consisted of installation of 35 wooden storm windows, all of which were equipped with piggy-back UV protection. The sash priced in this report were one-over-one, 40 inches wide by 111 inches high. Tempered glass was chosen to reduce breakage in what was considered a high-vandalism area. Work was done in 1993.
MAKING HISTORIC WINDOWS LEAD-SAFE

Jeff Gordon
University of Illinois
Building Research Council
Champaign, Illinois

Carol J. Dyson
Preservation Services
Illinois Historic Preservation Agency
Springfield, Illinois

Introduction

Highly visible to the public, historic windows are valued by preservationists as one of the most significant character-defining elements on the exterior of buildings. Quality materials, delicate muntins, true divided lights, hand-crafted cabinet-grade joinery, durable mechanisms, and quality hardware all contribute to the significance of historic windows.

Historic windows also are often coated with lead-based paint. The issue of lead-based paint is becoming increasingly important in renovation projects as the country focuses on this environmental health problem. Given the perceived complexity of this issue, many architects, preservationists, and building owners rely on environmental engineers or consultants, who may have little knowledge of historic preservation, to solve lead paint issues. Preservation project planning that is overly dependent on environmental considerations can lead to unnecessarily high abatement costs, and may cause the unnecessary removal and replacement of windows and other significant fabric in historic buildings. Lead paint is a serious issue, but one that must be incorporated into an integrated decision-making process about historic windows. Preservationists must educate themselves and use their new knowledge of lead paint issues to empower their decision-making.

Retaining historic windows is entirely compatible with lead hazard reduction. The purposes of this paper are threefold: first, to provide an overview of the issues surrounding lead-based paint and how they affect windows; second, to address the technical procedures, and specific treatment options for making historic windows lead-safe; and third, to examine the emerging lead-hazard reduction industry and make recommendations for the development of lead training that is compatible with historic preservation. Although many of the lead paint issues are similar for steel windows, this paper will focus on historic wood windows.

The Health Issue

Lead is a poison to humans, affecting virtually every system of the body. Once in the body from ingestion or inhalation lead is distributed via the bloodstream to red blood cells, soft tissue, and bone. To assess the extent of lead poisoning, blood lead levels are measured in micrograms per deciliter (\(\mu\)g/dl), is used. Symptoms of elevated blood lead levels in adults may appear around 40 to 50 \(\mu\)g/dl. At higher exposure levels, lead poisoning can cause convulsions, coma, and even death.

Recent research has raised concerns about the neurotoxic effects of lead at levels below the
point when symptoms occur. Those who are most at risk from low level lead exposure are the youngest: fetuses, infants, and children under age 6. From conception to age six, the brain and the central nervous system are in a period of critical and rapid growth. There is evidence that lead can damage the central nervous system and impair brain development during this formative period, affecting IQ and attention span, and causing learning disabilities, hyperactivity, and behavioral problems. Based on this evidence, in 1991 the Center for Disease Control substantially reduced its "intervention level" for children to 10 \( \mu g/dl \).

The common cause of lead poisoning is the ingestion of lead-contaminated dust. The popular belief that children get lead poisoning from eating lead paint chips or chewing on windowsills is only partially correct. Dust is a more frequent cause. Children are at risk because their instinctive hand-to-mouth activities carry lead paint dust into their bodies. Lead dust from friable or deteriorated lead-painted surfaces, and the dust created by lead painted friction surfaces on windows and doors contributes to the lead dust levels in an older building. Lead accumulated in soil and tracked into homes by people and pets can also contribute to interior lead dust levels. Exterior soil, where children play, may contain high levels of lead due to deteriorated exterior lead paint from buildings, or decades-old residues from leaded-gasoline vehicle emissions.

Certain renovation activities, such as abrasive paint removal, dry paint preparation techniques, or demolition, can release tremendous amounts of lead dust into the air. The airborne dust presents an immediate hazard to workers, and the settled dust presents a long-term hazard to the residents. There are safer renovation alternatives, however, and this paper will explore some of the ones for window rehabilitations.

Brief Historical Background

In a letter to Benjamin Vaughn in 1786, Benjamin Franklin described the maladies of lead exposure:

The first thing I remember of this kind, was a general Discourse in Boston when I was a Boy, of a Complaint from North Carolina against New England Rum, that it poison'd their People, giving them the Dry Bellyach, with a Loss of the Use of their Limbs. The Distilleries being examin'd on the Occasion, it was found that several of them used leaden Still-heads and Worms and the Physicians were of Opinion that the Mischief was occasion'd by that use of Lead.

In 1724, being in London...I there found a Practice I had never seen before of drying a Case of Types, by placing it sloping before the Fire....I therefore sometimes heated my Case when the types did not want drying. But an old Workman observing it, advis'd me not to do so, telling me I might lose the Use of my Hands by it ....

When I was in Paris with Sir John Pringle in 1767, he visited La Charite, a hospital particularly famous for the Cure of that Malady, and brought from thence a Pamphlet, containing a List of the Names of Persons, specifying their Professions or Trades, who had been cured there. I had the Curiosity to examine that List, and found that all the Patients were of Trades that in some way or the other use or work in Lead; such as Plumbers, Glasiers, and Painters....You will see by it, that the Opinion of this mischievous Effect from Lead, is at least above Sixty Years old; and you will observe with Concern how long a useful Truth may be known, and exist, before it is generally receiv'd and practis'd on. [emphasis added]

While the toxic effects of lead were becoming noticeable by the early part of the eighteenth century, it was considerable time before this "useful Truth" was "generally receiv'd and practis'd on" in the United States. As Franklin stated, those involved with lead industries were aware of some of the hazards. One 1886 painters’ manual describes at length "painter’s colic": "This disease, the most common and the most dangerous to which painters are liable, arises with them from breathing in the fumes and handling the different preparations of white lead."2

Other countries acted to control lead in paint in advance of the United States. France was the first country to phase out lead in paint in the 1840s. Germany followed in the 1870s. Other developed countries followed suit early in the twentieth century. In the United States, unfortunately, it was not until 1978 that the use of lead-
based paint in residential housing was banned by
the federal government.

In the meantime, lead remained an important
component in higher quality paints. Paints made
with lead carbonate and lead oxides had excel­
| lent drying, adhesion, and covering attributes. So
| some paints contained up to 50 percent lead
| content. The hazards of lead in paint to workers
| were known to the painting industry, but no safer
| replacement that fully matched lead's positive
| performance qualities, was available.

The 1921 Radford’s *Cyclopedia of Construc-

| tion, Carpentry, Building, and Architecture*,
| clearly discussed the need for a painter to reduce
| unnecessary exposure to lead paint. Some of the
| safety tips are still relevant today.

The painter is exposed in a peculiar degree
to the danger of poisoning. In his case
especially, cleanliness is an absolute
essential of continuous health. White lead,
for example, is a deadly poison....Lead
poisoning is caused by minute particles of
lead which are absorbed into the system
through the stomach....It is much easier to
prevent than to cure lead poisoning.

The first thing to be observed by the
painter is to avoid eating or even taking a
chew of tobacco until after he has taken off
his overalls and thoroughly washed his
hands.

A later chapter goes on about these hazards:

Men have become confirmed invalids and
cripples....through the effects of what is
known in as lead colic. The question of an
efficient substitute for white lead, is
therefore, one of literally vital importance.
It has frequently asserted that there is no
substitute for....carbonate of lead.

Fifty years later, in 1971, Congress passed the
Lead-Based Poisoning Prevention Act. By
1978, fully 200 years after Benjamin Franklin's
observation, restrictions were fully in place and
the use and manufacture of lead-based paint was
banned for residential housing. Because lead
had already been successfully removed from
gasoline in 1976, the primary focus of lead
poisoning prevention programs over the last
twenty years has been on lead paint in housing.
In an attempt to quantify the extent of the
problem, the US Department of Housing and
Urban Development (HUD) estimated in a 1990
report to Congress that 90 percent of privately
owned dwellings built before 1940 had surfaces
with lead-based paint (Table 1).

Amendments were made to the Lead-Based
Paint Poisoning Prevention Act throughout the
1970s and 1980s. During this period, several
larger cities and some states also began develop­
ing prevention programs. As the country gained
experience from the initial efforts to deal with
the lead-based paint problem, it became clear
that the immense scope of the problem required
a new framework for addressing lead-based
paint hazards. The high cost of abatement
treatments and the hazards posed by unsafe lead
paint removal techniques encouraged Congress
and the regulatory agencies to re-address the
issue. The result was the Residential Lead­
Based Paint Hazard Reduction Act of 1992,
commonly referred to as Title X. Within this act,
Congress provided a framework for the develop­
ment of sensible and effective lead hazard
control programs. Recognizing that the full
abatement of all residential buildings would be a
cost-prohibitive goal for our country, Title X
marked a turning point in approach. Title X
establishes a goal of making housing lead-safe
rather than lead-free. Within that framework,
Title X instructed several federal agencies,
including HUD, the Environmental Protection
Agency (EPA), the Occupational Safety and
Health Administration (OSHA), and others, to
take specific programmatic actions. While some
actions are still in process, a number of Title X
programs and regulations have been enacted. In
brief, OSHA develops safety standards for lead
abatement workers, and EPA and local authori­
| ties regulate waste disposal. EPA also estab­

| lishes lead abatement training requirements,
while HUD develops standards for federally
funded housing. Some states have enacted their
own regulations. However, it is important to note
that most of the federal regulations are aimed at
the growing abatement industry and other than
federally funded or owned housing, but most
private renovation projects are largely unregu­
| lated. Appendix I summarizes many of these
regulations.
Lead-based Paint Hazards

A lead-based paint hazard is any condition that results in an unsafe exposure to lead-contaminated dust, lead-contaminated soil, or deteriorated lead-based paint. The presence of lead-based paint in a building does not present a lead-based paint hazard. Painted surfaces in good condition do not contaminate a building. Surfaces that generate paint chips and/or lead-bearing dust contribute to lead-based paint hazards.

There are three general categories of conditions that constitute lead hazards. Windows can fall into all three of these lead-based paint hazard categories:

Deteriorated Paint
Peeling, flaking, chipping, and chalking lead results in lead-based paint hazards. Falling paint flakes and chips are friable and are rather quickly converted to smaller particles and dust, contaminating the interior or exterior environment. The causes of paint deterioration, such as roof leaks, plumbing leaks, and lack of maintenance, are the root sources of many lead-based paint problems. Like any painted surfaces, windows are subject to paint deterioration. Condensation on windows and temperature differentials can contribute to the deterioration cycle.

Friction and Impact Surfaces.
Lead-based paint can be released into the environment through abrasion, impact, and friction. There are many building components that are subject to these forces, particularly painted windows, floors, stair treads and risers, doors, and some trim elements. Operable windows have friction surfaces. The operation of double-hung windows abrades the paint from the sash, the stops, and the window channels of the jamb. Other types of operable windows, including casement and awning windows, have friction and impact surfaces, as well.

Accessible and Chewable Surfaces.
The principal source of lead-based paint poisoning is from lead dust. It is also possible for a protruding surface, at a height accessible to the mouths of small children, to be a source of lead poisoning. Interior window sills, because of their protruding profile and height from the floor, are one of the best examples of an accessible and chewable surface (See Figure 1 for identification of window components).

Because older windows can fill all three of the above hazard categories they are often recognized as a source of lead-based paint hazards. As state and municipal lead hazard reduction programs have developed since Title X, the necessity of treating windows has become a common theme. Indeed, it is a rare residential lead hazard reduction project that does not address window treatment.

Evaluation of Lead-Based Paint Hazards

Lead has historically been a common component in paint. Although lead paints were no longer manufactured or sold after 1978 in the United States, their use had already begun to decline by the 1950s. In 1990, HUD estimated the percentage of U.S. housing with lead-based paints for various construction periods (Table 1).

While any painted surface may potentially hold lead-based paint, some locations are more likely than others. Enamel interior paints, such as those found at kitchens, bathrooms, trim, doors and windows, are more likely to contain lead paint than matte finish flat paints. Lead paints were also prized for higher quality exterior use because of their good rate of coverage and durability. Figure 2 provides some indication of a typical distribution of lead-based paint in an historic house. However, the only way to find

<table>
<thead>
<tr>
<th>Construction Year</th>
<th>Total Occupied Units</th>
<th>Percent with Lead-Based Paint</th>
<th>Average Surface Area with Lead-Based Paint on Interior and Exterior Surfaces (ft²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1960-1979</td>
<td>35,681,000</td>
<td>62%</td>
<td>466</td>
</tr>
<tr>
<td>1940-1959</td>
<td>20,476,000</td>
<td>80%</td>
<td>1,090</td>
</tr>
<tr>
<td>Before 1940</td>
<td>21,018,000</td>
<td>90%</td>
<td>1,996</td>
</tr>
</tbody>
</table>

Table 1.6
out if any particular painted surface or building component contains lead-based paint is to test for it.

Two types of evaluations can be performed to identify hazardous levels of lead in and around buildings: paint inspections and risk assessments. Typically, a trained and certified professional is required to perform the evaluation, though regulations vary by state. The two methods differ in the approach and goals of the evaluation. A paint inspection is a surface-by-surface investigation to determine the presence of lead-based paint. An inspection answers the questions: Is there lead-based paint in the building, and where is it located? A risk assessment is an investigation to determine the presence of lead-based paint hazards. The distinction lies in the word “hazards.” A risk assessment focuses on the sources of, or potential for, lead contamination rather than attempting to establish a comprehensive documentation of the lead-based paint poisoning. A risk assessment not only addresses the location and condition of the lead paint, but also addresses who the building occupants are, and what risk the lead poses to them. A day-
care facility would obviously pose greater risk than an office building.

By combining both paint inspection and risk assessment in a comprehensive evaluation, a work plan employing the best mix of mitigation strategies can be devised. Figure 3, reprinted from the *HUD Guidelines*, examines the decision-making logic for evaluations. It is revealing in its emphasis on historic preservation procedure. A combined paint inspection/risk assessment allows for informed decision making for both short-term renovations and long-term care.

**Evaluation - Windows**

With regard to windows, combining paint inspection and risk assessment can be particularly valuable. Because operating windows can generate dust through friction, inspecting the lead content of the paint through XRF (X-Ray Fluorescence) testing on both the sash and jamb helps determine the potential for hazardous conditions, and speaks to the hazards associated with any clearly deteriorating paint. To investigate the extent of existing hazards, the risk assessment technique of dust wipe sampling is required. Dust wipe sampling, which measures the lead in dust in units of micrograms per square foot (\(\text{g/ft}^2\)), is commonly performed on three horizontal surfaces: floors, window sills, and window troughs. HUD has established dust lead levels for each type of surface above which the condition is considered a hazard. In Illinois, a HUD funded pilot program is developing a methodology and work force to cost-effectively address lead paint hazards in low-income
**Figure 3. Decision-Making Tree. (Adapted from 1995 HUD Guidelines, 3-10.)**
<table>
<thead>
<tr>
<th>Type of Surface</th>
<th>Number of Samples</th>
<th>Median Lead Level (µg/ft²)</th>
<th>HUD Hazard Level (µg/ft²)</th>
<th>% Samples Exceeding Hazard Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Floors</td>
<td>123</td>
<td>60</td>
<td>100</td>
<td>36%</td>
</tr>
<tr>
<td>Window Sills</td>
<td>105</td>
<td>445</td>
<td>500</td>
<td>47%</td>
</tr>
<tr>
<td>Window Troughs</td>
<td>55</td>
<td>11,510</td>
<td>800</td>
<td>95%</td>
</tr>
</tbody>
</table>

Table 2.

housing. The “Get the Lead Out” program has tracked the pre-intervention dust levels in the houses in the program. The following table presents preliminary data from the dust wipe sampling, along with the levels established by HUD. It should be noted that the majority of the low-income housing units chosen for the program have at least one child with elevated blood lead levels in residence, so some degree of hazardous conditions is anticipated.

The data is revealing as to where some of the hazards may be found. The median level on the floor samples is below the hazard level, with just 36 percent of the samples indicating a hazard. The median level on the window sills is quite close to the hazard level, with nearly half the window sill samples (47 percent) in excess. The median level in the window troughs, however, is about 14 times the hazard level, with nearly all the samples (95 percent) indicating a hazardous condition. While dramatic, these figures are not extraordinary; other programs have shown similar results.

Window troughs are a repository for lead dust. (See Figure 4 for a definition of the window trough area.) Lead chips and dust from the windows, and lead dust blown in from exterior paint surfaces or contaminated soil nearby, can be deposited on this horizontal surface. A contributing factor to the high lead levels in window troughs is infrequent cleaning. Window troughs are often neglected in regular cleaning regimens, allowing the accumulation of lead dust for months, or even years. This lack of frequent cleaning can result in extremely high levels of lead, and serious lead-based paint hazards.

In any rehabilitation or historic preservation project, the issue of lead-based paint should be a contributing factor in the window-treatment planning process. This is not to say it must be the only factor or even the decisive one. The decision-making process is one of integrating numerous factors to realize the most sensible and cost-effective approach.

**Lead Hazard Mitigation Options - An Overview**

Lead hazard reduction is classified into two basic approaches: abatement and interim controls.

*Abatement* is a strategy designed to permanently eliminate a lead-based paint hazard. The 1995 *HUD Guidelines* defines “permanent” as a treatment capable of lasting 20 years. Abatement activities can classified by four different treatments: 1) Complete removal of the lead-based paint from the surfaces. 2) Removal and replacement of the lead-based painted component. 3) Enclosure of the component or surface. 4) Encapsulant coatings: newly developed coating systems that have long life spans and do not fail as chalking or chipping surfaces. Most abatement project will use a combination of these treatments. Complete abatement of a building can be a very expensive proposition.

*Interim controls* is a strategy designed to make buildings lead-safe by temporarily controlling lead-based paint hazards. Also known as *in-place management*, the concept is relatively new to the field. Interim controls include specialized cleaning and dust removal, paint film stabilization, and the treatment of friction and impact surfaces. Upon examination, specific interim control measures also qualify as abatement techniques. This will be seen to be particularly true when we examine the interim control methods as they apply to windows. Often the most appropriate approach to lead hazard reduction is a combination of abatement and interim controls.
Sectional view of window (with no storm window) showing window trough area, A, to be tested. Trough is the surface where both window sashes can touch the sill when lowered. The interior window sill (stool) is shown as area C. Interior window sills and window troughs should be sampled separately.

Sectional view of window (including storm window) showing window trough area, A and B, to be tested. Trough extends out to storm window frame. The interior window sill (stool) is shown as area C. Interior window sills and window troughs should be sampled separately.

Figure 4. Defining the Window Trough. (Adapted from 1995 HUD Guidelines, 5-17.)
An interim control strategy is obviously very compatible with preservation principles, as it allows the retention of building components even with the presence of lead-based paint. At the same time, it must be stressed that interim control measures are fully effective only as long as they are monitored and maintained. With dedicated maintenance, interim controls can be effective indefinitely. Without regular evaluation and maintenance, lead-based paint hazards can re-emerge. This realization is also compatible with historic preservation principles, as comprehensive maintenance planning and execution represent the highest form of preservation.

**Before You Begin - Dust Control for Worker, Worksite, and Resident Protection**

Whether a project features abatement measures or interim controls in dealing with lead hazards, attention must be paid to the protection of workers, the building environment, and the residents. For this reason, three actions must be part of any work plan when disturbing lead-based paint:

- Adequate worker protection
- Containment of dust and debris
- Proper clean-up

With regard to each of these actions, lead paint dust is the “enemy.” Paint chips and lead paint attached to substrates are generally controllable in terms of human health exposure. Dust control measures are extremely important to protect workers, as well to safeguard the property and future occupants.

Knowledge of “low dust” work techniques and worker protection is critical to any project that disturbs lead-based paint. The difference in dust generation between various techniques can be like night and day. Improper paint removal methods can produce dangerous levels of airborne dust well in excess of OSHA hazard levels, placing renovation workers in jeopardy. Wet sanding and wet scraping, as compared to performing these activities dry, greatly reduces the amount of airborne dust generated. The same work can be accomplished at a fraction of those dust levels. Controlling dust generation is central to worker protection. When wet scraping, the surface is first misted before scraping. Wet sanding can be accomplished by misting the surface and then sanding with a sponge sanding block that is saturated with de-glossing liquid. There are also newly available sanders with small integral HEPA (High Efficiency Particle Air Filter) vacuums designed to contain the dust generated. The 1995 HUD Guidelines contain helpful discussions of safe work techniques and worker protection.

In addition to protecting workers, controlling dust generation is also central to preventing lead contamination of a building. There is substantial evidence that some renovation work has cause significant lead contamination. Limiting the amount of dust generated, and the containment and removal of all paint chips and incidental debris, is vital to providing a safe, habitable building upon completion of renovation. Containment when working on windows can usually be accomplished by extending one layer of plastic sheeting five feet beyond the perimeter of the window, and sealing the window opposite the side from which the work is being done. Chapter 8 of the 1995 HUD Guidelines discusses appropriate measures for worksite preparation.

Finally, proper clean-up procedures following renovation work ensure a lead-safe environment. In some lead hazard reduction programs, specialized cleaning alone has proven to be an effective approach to reducing blood lead levels in children. Again, dust control is critical. Dry sweeping or using a conventional vacuum cleaner can spread lead dust rather than removing it. HEPA vacuums differ from conventional vacuums in that they contain high-efficiency filters that are capable of trapping small particles of lead, and are recommended following renovation work that has disturbed lead-based paint. Mopping and other wet cleaning using a high phosphate content detergent, tri-sodium phosphate (TSP), or other specialized cleaners designed for lead, is also recommended. Chapter 14 of the 1995 HUD Guidelines details cleaning procedures.

In the following section, specific window treatment options are discussed. The activities associated with these options are not far removed from (and in some cases are identical to) regular window rehabilitation work. What
distinguishes lead hazard reduction work from typical renovation work is not so much the specifics of rehabilitation techniques, but rather the emphasis on minimizing dust generation, worker protection, containment, and cleaning. When the importance of these requirements is appreciated, and when the associated extra measure of care is applied to the work process, renovation work can be accomplished in a lead-safe manner.

**Lead Hazard Reduction for Windows**

**Abatement Techniques**

As previously stated, abatement is generally recognized as the removal of all lead-based paint from a building component, or the removal and replacement of a painted building component.

**Window Replacement.** Replacement of the entire window unit permanently eliminates any lead-based paint hazard. It is a common activity in rehabilitation projects, with an entire industry heavily promoting the activity. A desire to increase energy efficiency or replace a deteriorated window is often a principal motivation in window replacement. However, window replacement results in the loss of historic fabric. This is not preferred in historic preservation work, and may be altogether unacceptable for significant windows in good or repairable condition. Additionally, window replacement can be costly. Removing an old window and preparing the opening for a new window can be a dirty process, and attention to dust generation, containment, and clean-up is critical.

**Paint Removal.** Stripping all the paint from a window unit also can permanently eliminate a lead-based paint hazard while retaining the historic fabric. This can be a very hazardous activity, however, generating excessive amounts of lead dust. The following paint removal techniques should be avoided because they expose workers and the environment to excessive lead levels:

- Open flame burning
- Machine sanding or grinding
- Abrasive blasting or sandblasting
- Dry scraping
- Chemical paint removers containing methylene chloride

Heat guns operating below 1,100°F will not produce lead fumes, but the accompanying scraping activity still generates airborne particles requiring respiratory protection. There are also mechanical tools available with HEPA vacuums attached. Chemical removal, caustic and non-caustic, can be employed, and usually results in less leaded dust generation than other removal methods. In the case of chemical paint removal, worker protection is again critical. Wet planing can be used to remove selected paint from removed sashes, but may not be practical for an entire window. Wet scraping and wet sanding are techniques designed to remove deteriorated paint and are included in the interim control section below under "Paint Stabilization."

Off-site paint removal is preferred, since most of the contamination and residues are generated away from the building. Removal of the window components for off-site stripping must be done carefully, both to protect the component and to minimize the amount of airborne lead. Components that have been stripped with caustic strippers must be carefully neutralized before repainting. Potential damage to window components during tank stripping include damage to the hardware, broken glass, weakening of glue joints, and swelling of the wood fibers. Complete chemical stripping may therefore need to be combined with window repair programs.

Of all window treatment methods, on-site stripping can be the most hazardous to workers, and requires a high level of knowledge, training, and worksite containment. Generally, complete paint removal on a window unit is an expensive technique.

**Interim Control Techniques**

Interim controls address controlling lead hazards as compared to the elimination of the paint or the painted component. By retaining historic fabric, interim controls are often the preferred approach in historic preservation work. When interim controls are employed, a regular program of monitoring and maintenance should be subsequently followed.

**Paint Stabilization.** Paint stabilization is at the heart of interim control strategies. If paint deterioration is not overly extensive, this tech-
nique can be an effective approach. Paint stabilization is similar to normal good maintenance of painted surfaces with a few exceptions to address lead dust and debris control. The most important distinction is that the surface should first be misted with water before scraping or sanding to help control dust. Wet scraping is commonly used for stabilization. Wet sanding using a sponge sanding block saturated with de-glossing agents can help feather out the edges. Preparation is followed by a good quality primer and topcoat. Localized containment of the debris is important. Other factors that affect paint preparation (moisture content of the substrate, compatible coatings, etc.) are important, as with all painting jobs. If there is an obvious source of the deterioration (such as a moisture source), it should be dealt with first. Good quality paints are necessary with repainting to keep the painted surface in good repair. Specialized encapsulant paints are designed to cover lead paint as an abatement technique. They are highly durable and their elastic nature is intended to coat the surface and not fail as underlying cracks appear; as such they are considered abatement techniques rather than interim controls. Encapsulants are more expensive than regular paint, and their thickness can obscure the fine details of the surface they coat. Safe but thorough paint preparation before repainting, and the use of high-quality paints may serve just as well as encapsulants for hazard reduction. They are not, however, appropriate for friction surfaces.

Paint Removal from Friction and Impact Surfaces. While paint stabilization is an acceptable approach for most window components and surfaces, even intact lead-based paint is a hazard on friction surfaces. Paint on the sash, jamb, parting bead, and interior stop is abraded each time the window is opened or closed. Treatment of the friction surfaces, along with paint stabilization on the remaining surfaces, will retain historic fabric while rendering a window lead-safe. Effective treatment of the friction surfaces consists of the following steps:

1. The interior stop holding in the lower sash should be misted, scored with a razor knife along the edges, and removed. Some practitioners apply masking tape over the joint prior to scoring and removal to catch any paint that might chip off. In many lead hazard reduction projects, the stop is discarded and replaced. If the interior stop is considered a significant detail, its friction surface can be treated also.

2. The lower sash is removed. Paint is removed from friction edges, including the outer 1 inch on each face of the sash. Wet scraping is one method. Wet planing can also be quick and effective. Wet sanding with a sponge sanding block saturated with a de-glossing agent can be used to feather the paint edge around the newly cleaned surface. The edge of the sash, facing the jamb, is typically not painted, and does not require treatment. Limited chemical stripping may also be useful.

3. Paint on the friction surfaces of the jamb and parting stop are dealt with similarly, with wet scraping being one of the most practical methods. Chemical stripping of the jamb can also be used. The parting stop may also be removed, discarded, and replaced.

4. All window components are thoroughly cleaned, and the window reassembled.

Fixing Windows in Place. In some cases, operating double-hung windows may no longer be practical or desired. When sashes are fixed in place, the potential for contamination from the friction surfaces is eliminated. This can be accomplished by installing inconspicuous metal hardware or wood stops anchoring the sash to the channel of the jamb. Once fixed, the window is similar to any other trim element, and can be treated with paint stabilization techniques or encapsulant paints. This strategy is not generally appropriate for most residential property windows, as operable windows provide desired fresh air into the habitable spaces.
**Dust Control and Cleaning.** As we have seen, proper cleaning is a component of all lead hazard reduction work. On sound windows with intact painted surfaces, frequent dust control and cleaning, in and of itself, is an acceptable interim control technique. Cleaning window sills and troughs on a regular (twice-weekly) basis with TSP can successfully control lead-based paint hazards. This interim control technique can be guaranteed to be effective only when cleaning procedures are performed on a dedicated, scheduled, basis.¹⁰

**Treatment of Protruding Surfaces - Window Sills.** Window sills are the classic example of a “chewable and accessible” surface. Their height and shape makes them easily accessible to small mouths. They should receive an abatement level of treatment such as complete stripping (wet scraping, planing or chemicals). If the details of the sill are significant, or the removal of material is not preferred, an encapsulant paint can be used. Note that this is the only place where an encapsulant paint is recommended; encapsulants are not effective on friction surfaces, and thus not particularly applicable to window work in general.

**Combined Techniques**

Some abatement treatments, such as partial enclosures or replacements, can be combined with interim controls.¹¹

**Jamb Enclosure.** Commercial jamb enclosures, or jamb liners, are made of vinyl or aluminum. They enclose the jamb of a window and replace stops by providing new channels for sash to operate in. Jamb enclosures, together with the treatment of the friction surfaces on the existing sash, can be a cost effective treatment in cases where the wet scraping of the stops and jamb would be laborious. Figure 5 illustrates this technique. The removal of the sash and stops should proceed as described before, with care taken to control dust and paint chips. It may be necessary to cut the sash down slightly to accommodate the jamb enclosure. It is possible to cut a hole in the jamb liner so the existing pulley and sash weight system can be reused. The use of a pulley hole enclosure could mask an uneven cut. There is some visual loss with this treatment, but retaining the original sash minimizes the overall historic impact.

**Sash Replacement.** If the sash are badly deteriorated, it is possible to combine interim controls with sash replacement. Preparation and treatment of the jamb and stops should proceed as previously described. Sash replacement is costly, and results in the loss of historic fabric. It is not a dust-free procedure.

**Sash Replacement and Jamb Enclosure.** This treatment is simply a combination of the previous two: sash replacement combined with a jamb enclosure. At this point, we are getting close to an entire window replacement. By combining sash replacement with jamb enclosure, a more permanent control of lead-based paint hazards is achieved. However, due to the loss of historic fabric and the intrusive appearance of the jamb liner, this is not the preferred approach for preservation projects.

**Window Trough Enclosure.** The window trough, or window well, is the horizontal surface directly under the sash, or between the sash and storm window frame (Figure 4). The window troughs of old windows are commonly “loaded” with lead dust. A thorough cleaning of the trough is the first order of business in any treatment. If the trough is in good shape, paint stabilization may be appropriate. Often, the window trough is weathered, or it has a broken and uneven paint coating. Such a damaged surface can be almost impossible to keep clean. Whenever performing interim controls on a

![Figure 5. Jamb Enclosure. (Adapted from 1995 HUD Guidelines, 1-31.]

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window, it is valuable to leave a smooth, easily cleaned surface in the window trough for future cleaning and maintenance. A common technique is to enclose the window trough with aluminum coil stock that is back caulked and nailed into place. Figure 6 illustrates this treatment. It should be noted that covering the trough with aluminum is a low-cost approach. For a restoration project, covering the trough with a thin piece of wood is a better approach, but, depending on the thickness of the wood "liner," the bottom rail of the sash may need to be shaved off so that the sash locks where the rails meet still function. The wood liner must be sealed in place to prevent moisture intrusion.

Putting it All Together: Lead-Painted Windows and the Decision-Making Process

In any renovation project, the decision of how to treat the windows is based on a number of factors: occupant use, historic significance, condition assessment, energy considerations, and cost. The presence of lead-based paint should not be the determining factor in making window treatment decisions, but should be integrated with these other factors into the decision-making process. Only through an integrated thought process can the most appropriate and cost-effective decisions be made. The following sections discuss some of these factors. Figure 7 provides a table which examines lead hazard reduction options in light of other considerations.

Building Occupant

First, assess the risk to the occupants of the building and design an appropriate treatment program. Obviously a building that houses a daycare or young children should receive different consideration from an office or warehouse building. The intended occupancy of the building will particularly dictate the pertinent regulations that affect a project. (See Appendix I for a regulatory overview).

Condition Assessment

The next step is to determine the condition of the historic windows. Every window may not be easily preserved, but peeling paint can make a window look worse than it is. One preservation methodology is to carefully strip the paint of a representative window before making overall window condition decisions. On wood double-hung windows, the bottom rail or the bottom
<table>
<thead>
<tr>
<th>TREATMENTS ISSUES</th>
<th>INTERIM CONTROLS</th>
<th>COMBINATION TREATMENTS</th>
<th>ABATEMENT TREATMENTS</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Specialized Cleaning and Dust Control Maintenance</td>
<td>Fix Window in Place and Paint Stabilization</td>
<td>Treat Friction Surfaces on Sash &amp; Treat Friction Surfaces</td>
</tr>
<tr>
<td>COST OF TREATMENT</td>
<td>Low. Continuing maintenance critical, with some minor continuing cost.</td>
<td>Generally low. Depends on extent of deteriorated paint and window condition</td>
<td>Generally low. Depends on extent of deteriorated paint and window condition</td>
</tr>
</tbody>
</table>

Figure 7. Treatment Options for Lead Hazard Reduction in Historic Windows.
joints of the sash shows the most deterioration. Often those areas can be repaired with epoxies, regluing joints, or even complete replacement of the bottom rail. A window survey is an appropriate method to evaluate the overall condition of the windows in a building. Windows on the south and west facades may demonstrate the most deterioration due to temperature differentials and freeze thaw cycles. Windows on the north and east facades (or areas protected from the elements by neighboring buildings or porches) generally show less deterioration and are more easily retained and repaired.

Energy Efficiency
The lead paint hazard reduction treatments discussed within this paper present opportunities to improve significantly the energy efficiency of historic windows with methods such as weather-stripping, reglazing, fixing closed one or both sash, storm window installation, or even retrofitting with insulated glass.

Historic Preservation Considerations
The Secretary of the Interior's Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings are the preservation “conscience” of many historic rehabilitation projects. The Standards and Guidelines advise that deteriorated significant historic features, such as most windows, should be repaired rather than replaced. Replacement is appropriate only when the severity of deterioration requires it. The Standards and Guidelines go on to recommend “identifying, retaining, and preserving windows that are important in defining the overall historic character of the building.”

Because the retention of historic fabric within an historic building is critical in the definition of the building’s significance, the loss of historic fabric is considered a loss to the building’s integrity. With the removal and replacement of historic features, a building loses integrity and, therefore, significance. A well-matched replica is just that: a replacement. It is false, with no authenticity or historic significance.

In historic preservation projects it is important to first identify which features of the building are significant before making rehabilitation decisions. Historic windows are usually well-constructed with high-quality materials. They are often character-defining features that deserve preservation. The abatement technique of replacing historic windows, although occasionally appropriate on some elevations, or even on some buildings, should never be the first choice in a preservation project. Historic wood windows are often made of higher quality old-growth timber rather than fast-grow new wood. The cabinet grade construction of many historic wood windows also surpasses in quality average modern replacement sash. High quality historic steel windows are also made of higher quality steel than is usually utilized today. The hardware and hinges on historic windows are usually sturdy, well-designed and are often made of brass or bronze. The pulley and weight systems of double-hung windows are extremely durable and will far outlast today’s spring-balance systems.

New technologies make even the most careful replications fall short. For one, historic glass imparts a quality that cannot be replicated with modern float glass. Whether it is wavy early nineteenth-century glass, or distinctly clear and polished plate glass of the late nineteenth and early twentieth century, the glass in historic windows often imparts a distinctive quality to the light passing through it. Early divided light windows have slender and delicate hand-crafted muntins that make the bulkier muntins in some modern insulated glazing units look like prison bars in comparison. On the exterior of a building, the appearance of divided light windows also varies greatly from that of modern applied muntin systems. The different panes of glass in divided light windows are all on slightly different planes and each reflect light differently. This gives divided light windows on a facade a lively, almost jewel-like appearance, which is impossible to replicate with the flatness of a single sheet of modern glass with applied muntins.

The significance of historic windows also relates to the facade on which they're located. Often preservationists accord a higher significance (and therefore a higher priority for repair and retention) for windows on highly visible facades. On high rise projects, once again the windows most visible to the public — those on lower floors, have the most significance and may deserve the highest priority for restoration. Similarly those windows that are part of highly
formal interior spaces have more significance than those in less public spaces.

Cost
Cost is always a factor in construction projects. The cost of rehabilitating historic windows directly relates to the window’s condition, and the amount of repair necessary. For windows in good condition, full abatement measures, such as replacement of the historic windows, are typically more costly. Of the window retention techniques discussed in this paper, full-stripping and complete window repairs (including epoxy and joint repairs) are more expensive than on-site installation of jamb and trough liners and paint stabilization.

The Future of the Lead Hazard Reduction Industry

There are two important questions related to the lead hazard reduction industry that critically affect the cost and quality of historic building renovations in general, and window work in particular. First, who is the primary decision-maker when lead paint issues affect building renovations in general, and window work in particular? Second, who should be doing the actual work on historic windows?

Who does one call when renovation involving lead-based paint is planned? Who is most qualified? In most of the country, the lead-hazard reduction industry is in its youth, still changing, growing, and evolving. As the industry has emerged, one may legitimately question the application to preservation projects, and to historic window projects in particular.

Title X gave EPA the responsibility to promulgate regulations on the training and certification of lead hazard reduction inspectors, risk assessors, contractors, and workers. This effort was designed to work under state jurisdiction, with EPA providing accreditation for the state training programs. EPA’s proposed rules were first published in 1994 and a minority of states have produced accredited training programs. EPA published the final rule on training and certification, sections 402 and 404 of the Toxic Substance and Control Act (TSCA), in August of 1996.

The final regulations state that training and certification is required if one is performing abatement work. This means any set of measures designed to permanently eliminate lead-based paint hazards. (“Permanently” is defined as lasting at least twenty years.) Abatement is presumed in the following projects:

- Projects for which there is a written contract stating that activities will permanently eliminate lead base paint hazards
- Projects involving permanent elimination of lead-based paint or lead-contaminated soil and conducted by certified individuals
- Projects involving permanent elimination of lead-based paint or lead-contaminated soil that are conducted by firms or individuals who promote or otherwise advertise themselves as lead abatement professionals

The regulations specifically exclude renovation and remodeling from the category of abatement. Activities whose primary intent is to repair, restore, or remodel a structure, even if these activities may result in a reduction of lead-based paint, are not considered abatement. Clearly, this is an intentional loophole, which EPA fully recognizes. Indeed, the loophole originated when Congress drafted Title X. Rather than requiring regulations immediately for renovation and remodeling, EPA was directed to defer such regulation pending further study into the hazards of renovation activities. The first results of those studies are anticipated to be released in early 1997. Congress has expressly allowed EPA to amend TSCA at a future date so that it regulates renovation work as well.

One can conclude from the current regulations that certified and licensed contractors and workers may or may not be required based on the intent of the project. For instance, window replacement in the context of lead hazard reduction is abatement, and a licensed contractor is required. At the same time, literally thousands of old windows are replaced every week in the name of rehabilitation and weatherization, and in those cases a licensed contractor is not required. It is not the intent of the regulations to govern the window replacement industry, but rather to govern the lead abatement industry. In either case, ironically, the work of window replacement
and the potential for disturbance of lead-based paint may be identical. Under the current EPA training and certification regulations it is the intent of a project that is paramount: if it is defined as lead work, it is lead work; if it is defined otherwise, it is not lead work.

In the previous section, the decision-making process for window treatments was discussed. It called for a thought process that integrated several considerations: building occupancy, historic significance, window condition, lead hazards, energy efficiency, and cost. If decisions are made using this integrated thought process, exactly what is the intent of the resulting project? It is not solely lead abatement, nor is it solely renovation. Rather, it is somewhere in between — renovation that is informed about lead hazards. When lead work is part of a larger renovation project, defining the final intent of the resulting project, and whom to hire to do the work, would seem to be at the discretion of the project manager. The “loophole” is wide open.

The Need for Different Kinds of Training

It is not the intent of this discussion to suggest that the “loophole” be used indiscriminately, nor that training is not necessary. Lead is a hazard, and proper training is vital. In any renovation project that disturbs lead-based paint, the applied knowledge of the architect, contractor, and workers, particularly as it relates to dust generation, containment, and cleaning, is critical.

Responsible stewardship of a building includes attending to the environmental hazards the building may present, the protection of the workers who work there, and the protection of present and future users/residents. There is a need for lead-paint risk assessors who are knowledgeable about both lead paint and preservation, even if the preservation community has to train its own. The preservation community needs to empower itself with more information about lead issues if it does not want to lose control of repairable historic building fabric.

Preservation-Oriented Risk Assessment Training

The earliest decisions about lead hazards in a building are often the most critical to the final outcome. Those decisions are often abdicated by the architect and preservationists overwhelmed by perceived regulatory and liability encumbrances. Decisions that affect significant historic fabric are turned over to environmental engineers, or the lead abatement industry. Unfortunately for historic buildings, the current lead inspection, risk assessment, and contractor training is aimed towards the abatement industry, and not towards preservation. This does not have to be so. The goals of hazard-reduction and interim controls can be made compatible with the preservation goals of retaining historic fabric.

Preservationists and architects must fully understand the lead problem. An accurate understanding of what regulations apply and how lead paint hazards affect a specific historic building is part of the risk assessment process. So is designing a rehabilitation or maintenance treatment that can retain historic features in place rather than remove them. Preservationists should initiate the development of specialized lead inspection and risk assessment training to focus on preservation-compatible techniques and favorably addresses historic fabric retention issues.

Lead Awareness for Contractors and Workers

In addition to risk assessment training, contractor, supervisor, and worker training for lead paint is also directed toward the abatement industry. Often, the companies that have entered this field are environmental companies whose previous experience is in asbestos abatement. While this is starting to change in some parts of the country, it remains true to a remarkable extent. These companies employ environmental workers who are well informed about personal protection, worksite containment, and waste disposal, but are not necessarily skilled carpenters or painters. Furthermore, the cost of environmental abatement companies can be substantial.

Contractors and workers with high levels of skill in carpentry, painting, and other renovation activities are valued in the renovation field. However, significant training costs, the fear of bewildering regulations and burdensome worker protection requirements, and spiraling insurance costs all discourage contractor and worker
training. Not surprisingly, few have completed accredited lead training programs.

Insurance, in particular, is a major obstacle to the industry. To illustrate this point, assume two rehabilitation contractors — A and B — who do the same type of work. Both take out general liability insurance with the typical exclusion for environmental work. Contractor A determines to train his workers for lead issues, while contractor B does not bother. A pays the price in training costs and lost production, but then can say the company is certified for lead work. At that point, Contractor A must close the environmental exclusion in his liability coverage, and his insurance costs skyrocket $10,000 to $20,000. Contractor B, who is untrained, sees no such penalty. The outcome of this scenario is backwards. Contractor A trained his workers to protect themselves and prevent contamination of buildings and their residents during rehab activities, but must pass substantially increased insurance costs on to his customers. Contractor B’s workers may not be aware of lead-safe techniques and pose a greater liability risk, yet B’s insurance costs are lower. For renovation contractors, the current insurance system discourages any kind of training or intentional lead work.

It would take years of training for a lead abatement worker to learn and develop the skills to perform high quality preservation carpentry. In contrast, it takes only two days to train a skilled preservation carpenter on how to perform his existing work in a lead-safe manner. It is not additional skills that need to be learned, but rather how to employ those skills and how to approach the work just a bit differently to avoid lead contamination. Specifically, this type of lead awareness training would include:

- Learning techniques to eliminate high dust levels when performing renovation work. Nearly all renovation activities can be performed without approaching levels of airborne dust defined by OSHA as hazardous
- Recognizing those activities that are hazardous, like demolition and paint stripping, and proper worker protection in those cases
- Confining a work area and containing debris from lead-based paint
- Emphasizing proper cleaning techniques; replacing the broom and shop vacuum with a mop and HEPA-vacuum
- Monitoring work with pre-renovation and post-renovation dust wipe samples; ensuring a safe completed product and confirming the efficacy of the workers

For most renovation work that deals with lead-based paint, the work force should be skilled craftsmen or maintenance workers familiar with lead awareness training. This is particularly the case for historic preservation projects, where the retention of historic building fabric requires working with lead-based paint on a regular basis.

Even after hazard awareness training is common among preservation craftsmen, there still remains a need for environmental abatement contractors in the rehabilitation industry. There will always be rehabilitation and abatement projects where the disturbance of lead paint is so substantial that the use of trained environmental and abatement specialists is necessary.

Today, however, lead abatement work is a small fraction of the renovation, remodeling, rehabilitation, and preservation work to older buildings. The issue of lead awareness training within the renovation and rehabilitation industry is critical.

The Role of the Preservation Community

The historic preservation community can address lead-based paint hazards in the existing building stock. Preservationists should propose, develop, and support training and related programs toward this goal including:

- Specialized lead inspection and risk assessment training combining lead issues with preservation values. Preservationists should train both themselves and others in risk assessment skills that fully incorporate preservation into the equation
- Lead awareness training programs, distinct from lead abatement training, providing information on lead-safe renovation practice to a target audience of existing renovation, remodeling, rehabilitation,
preservation, and maintenance contractors and workers

- State and local initiatives to promote the training of the rehabilitation work force
- Public education efforts to create demand for lead-safe renovation contractors in the private sector
- Development of appropriately priced insurance policies designed for renovation contractors that recognize the inherent benefits and reward the implementation of lead awareness renovation training.

Conclusions

Lead paint is a complex issue that is of growing concern within the preservation and construction industry. Preservationists must fully educate themselves regarding this issue if they wish to continue to be a full partner in the decision-making processes affecting historic building fabric. Historic windows are particularly endangered under lead abatement programs, because of their friction surfaces and enamel paints. However, under the guidance of Title X, the movement within the regulatory climate is towards an emphasis on interim controls, not full abatement. Title X and 1995 HUD regulations specifically recognize that to make all historic housing lead-free rather than lead-safe would be cost prohibitive. Interim controls are recognized as a cost-effective way to address lead risks. This is good news for those concerned with historic preservation. The two goals of retention of historic building fabric including windows, and cost-effectively making a structure lead-safe, can both be met within today's regulatory climate. Included within the body of this paper and Appendix II are techniques for making historic windows lead-safe in a cost-effective manner. Most of these techniques are recognized by HUD in their 1995 Guidelines.

Almost all historic buildings and their windows are affected by lead paint. It is important that preservationists take an active role to develop and promote preservation-oriented lead awareness education. This way, fewer architects and preservation advocates will avoid making treatment decisions affecting lead-painted historic windows, due to confusion about what is actually required. Ironically, the regulatory climate for the average rehabilitation project is not as onerous as many believe. Even so, window decisions are regularly delegated to environmental engineers or abatement contractors who have with no experience in, or loyalty to, preservation. Rehabilitation decisions affecting historic windows should be made as part of a comprehensive approach; lead-paint hazard-reduction should be only one of many criteria evaluated.

To play a positive role in the lead-paint abatement process, preservationists must first educate themselves. Second, they should develop specialized lead risk-assessment training that incorporates preservation values. Third, they should help to promote and develop lead-safety and awareness programs for the rehabilitation workforce. Informed decision-making and a lead-aware workforce could provide the key to keeping rehabilitation work both lead-safe, affordable, and preservation-oriented.
Appendix I

Guidelines and Regulations Affecting Lead-Painted Windows

This appendix discusses many of the federal regulations, guidelines, and task forces that affect lead abatement. It is important to note that except for federally owned or assisted housing projects, few of these guidelines and regulations are intended to regulate non-abatement rehabilitation activities.

The guidelines and regulations do intend to protect those at highest risk, workers involved in lead work, young children and pregnant women. HUD Guidelines are valuable sources of information and are considered "the state of the art" in terms of lead work, although they do not directly regulate most projects. No matter what type of project is involved, OSHA regulations are intended to protect workers from dangerous levels of lead exposure, and RCRA and state and local disposal regulation are intended to prevent the inappropriate disposal of large quantities of hazardous waste.

Title X

The Residential Lead-based Paint Hazard Reduction Act of 1992, otherwise known as "Title X," was enacted by Congress in 1992. Title X established a framework for sensible and effective lead hazard control programs to ensure that housing became lead-safe instead of lead-free. The current OSHA, EPA, and HUD regulations and guidelines reflect that change in approach. This is very good news for historic preservation. Rather than full abatement procedures that might dictate removal of historic fabric, lead-safe techniques can retain historic fabric utilizing interim control methods.

HUD Proposed Rule for Federal Housing

Title X treats federally owned and assisted housing as distinct from private housing. In June of 1996, HUD published proposed rules on this housing, though the old rules still apply. Any residential project that receives federal funding falls under distinct regulations, which may differ depending on the federal funding program.

Disclosure Rule

As of 6 December 1996, the Disclosure Rule will be fully in effect. This regulation does apply to all private housing. Developed jointly by HUD and EPA as required by Title X, the Disclosure Rule dictates actions that should occur whenever pre-1978 housing is sold or leased. It requires the disclosure of all known lead hazards, the opportunity for a buyer to conduct an inspection, and the distribution of educational materials. It does not require any abatement or hazard control actions by either party. As the Disclosure Rule is integrated into real estate transactions, it will promote greater awareness of lead-based paint issues and a stronger private market for services.
OSHA Lead Exposure in Construction Rule
In June of 1993 OSHA issued 29 CFR Part 1926, Lead Exposure in Construction, Interim Final Rule. These regulations base levels of worker protection on exposure to airborne lead dust, and are targeted to workers in the construction industry. Dust levels can be monitored by air sampling, usually by an industrial hygienist. In establishing an action level of 30 mg/m³ (micrograms per cubic meter), and a permissible exposure level (PEL) of 50 mg/m³, OSHA is particularly concerned about protecting workers from abatement activities that generate large amounts of dust. When airborne dust exceeds these levels, significant worker protection efforts and compliance programs are required. While clearly focusing on abatement contractors, this regulation applies to all persons working with lead-based paint.

Lead-based Paint Hazard Task Force
Title X directed the Secretary of HUD, in consultation with the Administrator of EPA, to create a task force to make recommendations on lead-based paint hazard reduction and financing. The report of the task force, Putting the Pieces Together: Controlling Lead Hazards in the Nation's Housing, was published in July of 1995. The report provides an analysis of the existing state of the lead hazard reduction problem, and proposes national directions to address existing inadequacies. The report provides recommendations aimed at financing, liability and insurance, establishing standards of care, and educational needs.

Toxic Substance Control Act; Title IV
Title X gave EPA the jurisdiction for establishing regulations for lead abatement under the Toxic Substances Control Act. EPA recently published sections 402 and 404 dealing with state training programs and certification of inspectors, contractors, and workers. These sections exempt renovation and remodeling work from the category of abatement. A discussion of worker training is presented later in the paper.

Resource Conservation and Recovery Act
The primary Federal statute governing waste management is the Resource Conservation and Recovery Act (RCRA). Solid Waste generated by construction, maintenance activities, lead paint hazard reduction, and abatement projects are all governed by RCRA.

States governments administer RCRA and may enact hazardous waste requirements that are more stringent. A state agency charged with waste management is the best source of information for a project. Under RCRA requirements there are two exclusions to the full requirements (and high cost) of hazardous waste disposal: first, the household waste exclusion exempts solid waste generated as part of routine residential maintenance by a homeowner, resident or contractor. Second, small quantity generators who produce less than 100 kg/month (approximately 220 pounds/month) of hazardous waste are conditionally exempt and may handle such waste as nonhazardous.

Hazardous waste under RCRA is measured using the Toxicity Characteristic Leaching Procedure (TCLP) (40CFR261.24). This test measures how likely the waste is to leach and contaminate soil and water. On large scale projects that do not fall under the household or small generator exclusions, RCRA requirements can cause an unfortunate disincentive to preservation. If large quantities of lead paint are removed from historic materials such as wood windows, it must be disposed of as Category III concentrated hazardous waste. Paint stripper waste products, lead paint chips and dust frequently are in this category. However, if the entire building component is removed, it is likely to pass the TCLP test and as such can be disposed of in a much less costly manner than hazardous waste. State agency charged with waste management are usually the best source of information regarding which requirements relate to a particular project.

State and Local Ordinances
States have authority to regulate lead-based paint removal, disposal, and worker training and licensing. Most requirements address mitigation in the case of a lead poisoned child or the handling of hazardous lead waste. Local agencies may also have laws dealing with lead-based paint safety. Rarely are owners required to remove lead-based paint. It is important to determine which laws are in place, whether a project is defined as an abatement, and whether special contractors or permits are required.
Appendix II
Sample Outline Specifications

The following treatments can serve as a starting point for developing specifications for a lead-paint hazard reduction window project. They are adapted from specifications written by Pamela Hastings of the Illinois Department Of Public Health as part of the work protocol for the “Get the Lead Out: The Illinois Lead-based Paint Hazard Reduction Project.” They are cost-effective lead-paint hazard reduction treatments. These treatments were designed to address lead risks in an affordable manner in low-income housing. High-end preservation projects would probably require different treatments. These are only a few of the treatments possible and are only designed to serve as general guidance in developing treatment specifications for any building work program.

Stabilize Friction Surfaces
Tape over stop and frame joint. Cut through tape and remove stop. Discard stop and tape. Remove lower sash. Remove parting bead and discard. Wet scrape or wet plane painted friction surfaces and loose or deteriorated paint. Wet scrape all interior and exterior surfaces. Feather edges with a sponge sanding block saturated with de-glossing agent. Rinse and HEPA vacuum all visible dust and chips. Allow surface to dry. Reglaze as required. Rinse and HEPA vacuum. Allow surface to dry. Prime and top coat interior with a high quality paint from a single manufacturer.

Stabilize Paint
Wet scrape all interior and exterior components. Feather edges with a sponge sanding block saturated with de-glossing agent. Rinse and HEPA vacuum all visible dust or chips. Allow surface to dry. Reglaze as required. Rinse and HEPA vacuum. Allow to dry, spot prime, and top coat interior and exterior with high quality paint from a single manufacturer.

Remove Paint with Caustic Paste
Workers must wear protective gloves, full body protective clothing and face shields. Protect all areas not to be stripped. Apply caustic paste, organic solvents, or other chemicals, and any recommended coversheet in accordance with manufacturer’s specifications. Neutralize and rinse surface, if appropriate, in accordance with manufacturer’s directions. Allow surface to dry. Collect residue and rinse water in 55 gallon drums. Prime and apply topcoat.

Fix Closed and Stabilize
Screw meeting rails together using two #10 2-1/2 inch screws. Caulk to eliminate all air infiltration with siliconized acrylic. Wet scrape interior surfaces. Feather edges with a sponge sanding block saturated with de-glossing agent. Rinse and HEPA vacuum all visible dust and chips. Allow surface to dry. Reglaze as required. Rinse and HEPA vacuum. Allow surface to dry. Prime and HEPA vacuum. Allow surface to dry. Prime and top coat interior with a high quality paint from a single manufacturer.

Wrap Well and Stabilize
Wet scrape all interior and exterior window components. Feather edges with a sponge sanding block saturated with de-glossing agent. Rinse and HEPA vacuum all visible dust and chips. Spot prime bare wood with quick drying, water-based, clear sealant and topcoat with white alkyd paint. Back caulk and nail 0.027 aluminum coil stock in window well area. Drill two 3/8 inch weep holes in storm sash.

Replace Stool, Liners, Well, and Stabilize
Notes


4 Radford, 223.

5 Some specialized uses of lead paint are still legal, including paints for automobiles, and marine, farm and industrial equipment.

6 HUD Guidelines, Table 3.2, 3-7.

7 The principal tool for performing lead inspections is the XRF (X-Ray Fluorescence) gun. The advantages of XRF testing are speed (results are immediately available) and cost. As an advantage in historic preservation projects, it is non-destructive of the substrate. However, laboratory testing of paint samples can give a more accurate analysis. A disadvantage of XRF testing is that it will pick up any lead on a wall — even if it is safely encapsulated behind many layers of sound lead-free paint.

8 The economic benefit in energy savings between a single glazed (historic) window and the average double-glazed (replacement) window is not as high as many would expect when offset against the expense of new windows. The most significant cause of energy loss with historic windows is due to infiltration around the window. Most of the techniques discussed within this paper are compatible with, or are inherently, techniques that can significantly reduce energy loss due to infiltration and thereby increase energy efficiency.

9 Outline specifications incorporating some of the techniques described below can be found in Appendix II.

10 There are health department programs in both Wisconsin and Minnesota that are primarily housekeeping in nature. These programs help control lead paint hazards through building occupant education and training regarding lead-dust oriented cleaning techniques. It is not uncommon for a public health department to give away TSP, a bucket, and a sponge as an extremely low-cost interim control method of dealing with lead paint hazards.

11 These abatement techniques are discussed in Chapter 11, Interim Control, of the 1995 HUD Guidelines and, by inference, can themselves be described as interim control techniques. This emphasizes the point that interim controls consist of limited, modified, abatement techniques.

12 Due to cost, most of today's steel windows are produced from recycled steel. Source: conversation with Gail Wallace, Restoration Works, Inc., 19 October 1996.

13 The existing programs vary greatly. Check with offices to determine the nature and requirements of the state program, or whether a program is in place. A state or local program may differ or the interpretation of the program may differ from this present discussion.

14 It is primarily HUD projects that require full abatement, and even HUD's latest regulations have a greater emphasis on hazard-reduction through interim controls rather than full abatement.

15 Appendix I introduces many of the regulatory issues that affect lead-painted historic windows.

Bibliography


STORM WARNINGS:
HURRICANES, CODES AND NEW
CHALLENGES FOR HISTORIC BUILDINGS

Joseph L. Herndon
Principal
DMS Architects & Planners
Miami, Florida

The aftermath of Hurricane Andrew’s $35 billion damage to Florida and Louisiana included new far-reaching building codes and challenges to historic buildings windows and doors. Pioneered in Dade, Broward, and Palm Beach Counties in Florida, and now under consideration by the Southern Building Code Congress International (SBCCI) for all the southeastern states, new standards of resistance and protection are being applied to both replacement and existing windows and doors. Previous customary code waivers for historic buildings are being abandoned for strict and uncompromising standards that do save lives and property, but also challenge the Secretary of the Interior’s Standards for Rehabilitation and the practical alternatives available to owners, architects, and contractors of historic properties.

It’s just a matter of time

What makes the issue of hurricane protection so significant is research on hurricane frequency from the National Oceanic and Atmospheric Administration (NOAA), which has maintained statistical data since 1871 and can predict the frequency of hurricanes, especially significant Category 4 and 5 hurricanes that wreak disastrous impacts. In the case of South Florida’s historic Cutler Estate of Charles Deering, the predicted frequency of such a major Category 5 hurricanes as Andrew (22 August 1992) occurring in this area is at least twice per century, too frequent for ensuring the preservation of historic structures. Moreover, since 1900 three such hurricanes have already occurred (1926, 1945, and 1992). Similar data applies to all the Gulf and Caribbean coasts from Texas to Florida, and hurricane frequency is almost as significant for Atlantic coasts from Georgia to Maine (Figure 1). For small historic

Figure 1. Hurricane Mean Return Periods. The National Hurricane Center has maintained a statistical basis of hurricane activity since 1871 and is able to predict frequency of hurricanes for each part of the nation’s hurricane coastal area from Texas to Maine. The map illustrates the frequency of Category 3 hurricanes of 111-130 mph sustained winds, resulting in extensive damage. It ranges from nine years for the southern tip of Florida to 180 years for the Coast of Maine. Courtesy of the National Hurricane Center.
wood frame buildings along the coast, the lesson is clear. It is only a matter of time before disaster occurs. If the structure is worth saving, commitments to long range preventive planning, reinforcing stabilization, and window and door protection are essential to its long term survival. The recent hurricane codes address hurricane-proof construction and apply to contemporary and historic buildings alike. For the latter, the main line of defense is the provision of certified hurricane protection systems for all exterior openings, doors, and windows.

As the window goes, so goes the building

Solid doors provide more protection than glass doors, but once unprotected window glass is broken by pressure or flying projectiles, the entire building can simply explode. More than any other single factor, maintaining window integrity is the primary defense against hurricanes. In a recent article in Window and Door Fabricator, Jeff Stone, Ph.D., former Chairman of the Wind Load Committee for the Southern Building Code International (SBCCI) explains:

As hurricane force winds surround a structure, entryways and windows must withstand wind blown debris that can act as missiles to infiltrate a building. If the building envelope is penetrated, winds enter the building and generate increased internal pressures for the roof and walls, which can cause the structural integrity of the building to fail.

Figures 2 and 3 illustrate the impact of Hurricane Andrew on the historic wood-framed Richmond Inn in Dade County, Florida. The hurricane caused the building to essentially explode, destroying all three floors and verandas and scattering debris in mid-air and down wind. Similar destruction was experienced by most of the historic buildings in Andrew’s path. The original survey of historic buildings in this area was completed in 1981 and consisted of 204 sites. A follow-up survey of this area was made after Andrew to assess the damage, resulting in the removal of 102 buildings from the list because they were devastated beyond feasible restoration and partial reconstruction. All of these buildings were of wood construction and had no shuttering systems.

A matter of law

The new codes have been established to permit buildings to withstand the documented impacts of the worst storms. Given documented frequencies and intensities, these standards are adequate to assure the longevity of vulnerable historic buildings. Uniform standards for shutters designed to withstand 140 mph winds have been adopted into the South Florida Building Code, in effect in Dade, Broward and Palm Beach Counties, Florida, and are under consideration by the SBCCI, which already has set standards for windows susceptible to 90 and 120 mph wind loads, depending upon the height of the building. If adopted, the standards would apply to all the

Figure 2. Differential Pressure Impacts. Differential pressures caused by storms can cause a building to swell like a balloon. Penetration by flying projectiles can cause them to explode. Windows and doors are the most vulnerable and require impact resistant protection such as shutters. Overhanging parts of a building, which include dormers, verandas, balconies, and porches, are especially susceptible to damage caused by the wind’s uplift. Courtesy of DMS Architects & Planners, Miami, Florida.
southeastern states. These standards are based on a testing procedure for enclosures that requires a window to survive the impact of a 9 pound, 2x4 shot from an air cannon at 34 mph (Figure 4). The standards are applicable to all new and replacement windows and doors. Currently, requested waivers for existing windows have been denied unless the windows are provided with approved hurricane shutters. Certified Product Approval is required of all new window and shutter systems.

Historic Conflicts

To date, few certified products have been considered appropriate to the character of historic buildings by local preservation officials and State Historic Preservation Offices. Objections to currently available permanent shutters are based on the U.S. Secretary of the Interior's Standards for Rehabilitation, Number 9, which states:

New additions, exterior alterations, or related new construction shall not destroy the historic materials that characterize the property. The new work shall be differentiated from the old and shall be compatible with the massing, size, scale, and architectural features to protect the historic integrity of the property and its environment.

Figure 3. Historic Cutler's Richmond Inn Exploded from Internal Pressure upon Penetration of Glass and Windows. Hurricane Andrew (22 August 1992) destroyed most of the historic frame buildings in its path. Courtesy of Metro Dade County (Florida) Department of Parks and Recreation.

Figure 4. Impact Tests. The South Florida Building Code uses the impact test to determine a window's ability to withstand impact from wind borne projectiles, frequent in hurricanes. It requires that the protection system survives the impact of a 9 pound, 2x4, shot from an air cannon at 35 mph. With permission from DuPont Advanced Glazing Products.
Additionally, objections to compatible permanent shutter designs for buildings that historically did not have shutters are based on Standard Number 3, which states:

Each property shall be recognized as a physical record of its time, place, and use. Changes that create a false sense of historical development, such as adding conjectural features or architectural elements from other buildings, shall not be undertaken.

As a result, the provision of new permanent shutters for buildings that did not historically have shutters has been denied by preservation boards. For buildings that did have shutters, approvals have been granted for new shutters when the design is similar to the original. Since no wood shutter has yet been certified by hurricane Product Approval Boards, the result has been a reliance on temporary shuttering systems that are installed immediately prior to the hurricane occurrence. This is no panacea, as experience and Hurricane Andrew have demonstrated. Reliance on temporary shutters is too convenient, overused, and too often inadequate for the long term protection of both historic and contemporary properties.

**Shortcomings of temporary shutters**

The time and resources required for the installation of temporary shutters during a red alert are very serious problems, making the selection of a shuttering system the most significant concern for hurricane preparedness. Systems must be approved for use by local codes, must be appropriate to a building’s historic character, and must be practical. If an approved and appropriate system is too costly or requires more manpower, equipment, or storage than is available from the family or daily staff, it is impractical.

Many institutional, museum, or commercial buildings have approved temporary shuttering systems that remain uninstalled during a red alert because staff, after a reasonable contribution of time, abandon the site in order to tend to their own homes. It is a dire mistake to have a system that requires specialized skills, equipment, or lifting devices, since these will become increasingly scarce as storm landfall approaches. There will not likely be many trial runs, and trial by fire may be required from personnel who are not familiar with the systems. Elaborate systems are also expensive to install.

The new Hurricane Codes establish testing procedures for Product Approval and restrict installation of permanent shutters and initial installation of temporary shutters to qualified and licensed hurricane shutter installers only. Many officials recognize that future code refinements must add an Installation Time Efficiency Ratio for each type of temporary shutter and its application to specific buildings to establish the practicality of a pre-storm installation.

During Hurricane Andrew many recent multi-story glass office buildings suffered damage simply because their extensive and expensive temporary shuttering systems remained uninstalled when employees abandoned the sites to take care of their own homes. Likewise, institutional, public, commercial, and museum buildings are often more vulnerable than smaller residential buildings because of the time and expense required for installation by staff or employees. In hurricane prone areas, several hurricane warnings are given each hurricane season (July-November). Resources and costs dictate that the more elaborate and difficult the shuttering system, the least likely it will be installed before a red alert is given.

Vizcaya, a National Historic Landmark house museum in Miami, has an exemplary Hurricane Preparation and Recovery Plan. Unofficial estimates of initial capital costs for this three-story Classical Italian Renaissance Revival property are those costs associated with 600 square feet of storage area, a dedicated $80,000 bucket truck, and the shutters themselves. In addition, a red alert installation of the temporary hurricane shutters and battening down requires a crew of ten at least 16 hours, estimated at $7,500 for each installation. Since red alerts are issued normally 24 hours prior to landfall, only properties with in-place systems and experience personnel will likely be prepared adequately when the storm hits. Such resources of labor, equipment, and funding is rarely available for most historic properties.
Selecting a protection system

Consensus among experienced property managers suggests that a well-developed Hurricane Preparation and Recovery Plan should be in place for every property. Given the cost and time required for the installation of shutters, the selection and development of a hurricane shuttering protection system is the most significant component of hurricane preparedness and recovery. Selection of a shuttering system should be based on the following performance standards:

- The property must be totally battened down within a six to eight hour time window
- The source of all installation labor must be existing and available. These employees should be familiar with installation techniques and the time required, and should be informed of the time they will be allowed to leave to begin to prepare their own homes.
- Installation must be completed without the use of any special or off-site equipment.
- Temporary shutters for multi-story buildings should be able to be installed from the interior of the building through the window to avoid time consuming ladder or bucket truck crews.
- Temporary shutters must be stored in a readily adjacent dry location, ideally inside the building on the floor where they are to be installed.
- If permanent shutters are not used, seasonal (June through 1 December) installation and removal of shutter tracks should be considered because the time required for the installation of tracks is a substantial part of the overall installation time required.
- Permanent shutters that require the least amount of time to batten down should be used if possible. If historical or aesthetic considerations are paramount, sources of shuttering systems similar to those used on the building historically, or prototypes from other similar buildings of the same period, should be sought. Shutters should be removable and the installation should be reversible.

Although the previous discussion is most applicable to commercial, public, or institutional buildings, similar considerations exist for private residences. Additionally, private owners may be

Figure 5. Passive Protection Systems. This set of three double bronze French doors and transoms could not be protected by any available shuttering system without resulting damage to the architectural character of the ornate cast stone surrounds and capitals. However, because the metal mullions provided adequate bite, a single ply of poly vinyl butyral film (DuPont’s “Sentryglas”) will comply with Hurricane Code requirements. Since the historic muntin did not have adequate depth, a second layer of glass could not be added to make the laminate “sandwich.” Permanent cleaning instructions mounted on the window’s reveal were provided to minimize scratching of the surface by future window cleaners. Courtesy of Metro Dade County (Florida) Department of Parks and Recreation.
traveling and not available at the time of the storm, or may have no ready source of assistance necessary to complete the installation. For these reasons, the cost and complexity of installation and storm readiness are significant issues for historic property owners.

The future of passive protection systems

Some of the new and most promising approaches currently under development are permanent passive protective laminated glass using thin transparent layers of polyvinyl butyral (PVB) such as Dupont’s “SentryGlas” or Monsanto’s “SAFLEX.” These laminates can be permanently added to existing or new glass and require no pre-storm preparation; hence the term passive. They are ideal for large, complicated, institutional, museum, or commercial applications and for any metal windows. Since their installation requires that the window frame and mullions withstand the Hurricane Code impact requirements, the use of laminates isolated to bronze, aluminum, or steel windows only (Figure 5). Little advantage is provided to most existing wood windows because no matter how much resistance the glass may offer, the wood, joints, and mullions of the window must survive the 35 mph 2x4 cannon test. However, the SBCCI code requirement can be achieved by some wood window sash and muntins if laminated glass is used.

Currently, no double-hung wood window or historically appropriate wood replacement window has met the Hurricane Product Approval requirements. Although some are currently under development, it will still be some time before a true divided-light window with muntins of acceptable dimensions is available. However, as Hurricane Codes and standards become more prevalent across the coastal states, market demand will increase. A major convergence of hurricane and historic protection will result when availability and costs of historically accurate, hurricane-resistant wood replacement windows become competitive. Until then, the only recourse for historic buildings is the selection of an externally applied shuttering system for storm protection.

Available shuttering systems

Most available shuttering systems (Figure 6) are of the active type, i.e., they are physically attached and cover the opening. There are two active subtypes: permanent and temporary. Permanent shutters are retractable and are mounted either on the top or at the sides of a window. Contemporary top mounted shutters are roll-down solid metal panels, whereas historic prototypes would have been “Bahama shutters.” The contemporary roll-down shutter has received historic approval only in examples where the top-mounted box is either concealed by an historically appropriate awning or where the box can otherwise be concealed within the opening while maintaining the principal of reversibility. Contemporary side mounted shutters are solid metal “accordions,” whereas historic prototypes would have been side-mounted “Colonial shutters.” Again, few approvals of accordion shutters have been granted by preservation boards, with the exception of those that can be concealed within the opening and are reversible. Temporary shutters are usually of plywood (not legal in areas under the jurisdiction of the South Florida Building Code), corrugated metal, or polycarbonate panels. A new see-through steel screen, “Storm-Shield” (Figure 7), developed by Exeter, has been approved for metal windows with 0.5 inch glazing bite. It permits air flow and visibility through the screen, so that the window is visible from the exterior. These have the potential to be permanent shutters, replacing insect screens, but to date historic approvals have been obtained for seasonal installations only. Hurricane Code-approved temporary shutters require the installation of connectors and tracks along panels, which is the major pre-storm preparation effort of battening down. The construction time can be reduced by seasonal installations of tracks -- installation each 1 June and removal each 1 December, if permitted.

All temporary shuttering systems require immediately adjacent dry storage areas (Figure 8), organized storage racks with permanent markings on each shutter, track, connector, a map to assure quick fitting of matched pieces, and a team of installers who are familiar with the system and installation techniques.
Permanent shutters are more expensive but require the least pre-storm preparation—a significant consideration for large, institutional, and commercial buildings. Currently few of these systems are considered historically appropriate. Now under development are traditional wood shutters, made of imported dense tropical hardwoods with new joint details and locking and reinforcing hardware, but none have yet been approved. Figure 9 provides a detailed description of each type of permanent and temporary active shuttering system.

**Figure 6. Hurricane Protection Systems for Historic Buildings.** The following are the currently Hurricane Code approved Hurricane Protective systems, including passive protection systems and the two types of Active Protection Systems—Permanent and Temporary. Currently, no wood "Colonial" or "Bahama" shutter systems have met the requirements. Courtesy of DMS Architects & Planners.

**Figure 7. Steel Screen Protection for Historic Windows.** The photo illustrates the use of a semi-transparent steel screen that provides Hurricane Code Protection for metal windows. The screen is lightweight, can be installed from the interior of the window of multi-story buildings, and permits passage of light, air, and window visibility. Courtesy of Metro Dade County (Florida) Department of Parks and Recreation.
Figure 8. Storage for Temporary Storm Shutters. The drawing illustrates a custom piece of cabinet work, designed to provide some floor storage of hurricane shutters. The shutters are arranged on a rolling rack, each marked for identification. A map with an instruction diagram is permanently located on the interior door of the cabinet to assure proper location and fitting of matched pieces. The cabinet is designed to conform to the Spanish Mediterranean Revival character of the building, the interior architecture, and the furnishings. Courtesy of DMS Architects & Planners.

Figure 9. Comparison of Shuttering Systems. Shuttering systems should provide protection to all openings from impact, water infiltration, and wind load. Protection may include either active exterior applied shutters or passive glass lamination, or a combination of both. Results should comply with regulatory performance standards as well as historical appropriateness. Effectiveness is highly dependent upon correct installation. Under the South Florida Building Code, only licensed hurricane shutter contractors are permitted to provide shuttering systems. Check with your local code authorities before proceeding. Courtesy DMS Architects & Planners.

<table>
<thead>
<tr>
<th>TYPES:</th>
<th>INSTALLATION:</th>
<th>PRE-STORM TIME REQUIRED:</th>
<th>RELATIVE COSTS:</th>
<th>HISTORICAL IMPACT:</th>
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<tbody>
<tr>
<td><strong>ACTIVE</strong></td>
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<tr>
<td>A. DEMOUNTABLE</td>
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<tr>
<td>1. Corrugated Metal on Tracks</td>
<td>Pre-Storm</td>
<td>Considerable</td>
<td>Low</td>
<td>Minimal</td>
</tr>
<tr>
<td>2. Steel Screens on Tracks</td>
<td>Pre-Storm</td>
<td>Minimal</td>
<td>Moderate</td>
<td>Minimal</td>
</tr>
<tr>
<td>3. Plywood Panels</td>
<td>Pre-Storm</td>
<td>Considerable</td>
<td>Low</td>
<td>Minimal</td>
</tr>
<tr>
<td>4. Polycarbonate panels</td>
<td>Pre-Storm</td>
<td>Considerable</td>
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<td>Minimal</td>
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<tr>
<td>B. RETRACTABLE (Manufactured)</td>
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<tr>
<td>1. Overhand</td>
<td>Permanent</td>
<td>Minimal</td>
<td>High</td>
<td>Objectionable²</td>
</tr>
<tr>
<td>2. Accordion</td>
<td>Permanent</td>
<td>Minimal</td>
<td>High</td>
<td>Objectionable²</td>
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<tr>
<td><strong>C. TRADITIONAL</strong></td>
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</tr>
<tr>
<td>1. Wood Shutters</td>
<td>Permanent</td>
<td>Minimal</td>
<td>High</td>
<td>Depends on Style²</td>
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<tr>
<td>2. Bahama Shutters</td>
<td>Permanent</td>
<td>Minimal</td>
<td>High</td>
<td>Significant unless Original²</td>
</tr>
<tr>
<td>3. Aluminum Awnings</td>
<td>Permanent</td>
<td>Minimal</td>
<td>Moderate</td>
<td>Significant unless Original²</td>
</tr>
<tr>
<td><strong>PASSIVE</strong></td>
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<td></td>
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<td></td>
</tr>
<tr>
<td>1. Glass laminates</td>
<td>Permanent</td>
<td>None</td>
<td>High</td>
<td>None²</td>
</tr>
</tbody>
</table>

Notes:
1. Requires permanent connector installation, permanent or seasonal track installation and adequate dry immediately accessible storage for pre-sized numbered panels.
2. Plywood panels are not legal in jurisdictions under the South Florida Building Code.
3. In some instances, appropriate awnings can conceal visual impact.
4. No historically appropriate wood shutters are currently approved but are in development.
5. Permanent shutters and awnings that are not original are considered to have negative historical impact. Most shutters are common to pre-20’s buildings, Bahama shutters are more common to Key West and vernacular buildings, and aluminum awnings are more common to cottage styles.
6. Currently, glass laminates are approved for some metal windows only.

Conclusion

The frequency of major storms and the extent of damage they cause demonstrate that prior planning and preparedness are essential for historic properties if they are to be preserved over time. Documented experience also demonstrates that window protection is the most significant defense against devastation and loss of historic properties, and that excessive reliance on temporary shuttering systems is not a long-term solution. Individual property owners and managers should not be left to stand alone against such overwhelming odds, and preventive measures are more rewarding than any amount of recovery efforts. National attention of policy makers needs
to be brought to the issue of hurricane protection systems for historic buildings. All coastal buildings should have a developed hurricane protection plan and a protective shuttering system. Dependence upon inefficient and too often ineffective temporary shuttering systems should be reconsidered. Research assistance, funding, and incentives should be provided to enhance historically appropriate passive storm protection systems using wood replacement windows, to develop affordable permanent wood shutter systems. We must seek solutions that preserve both historical aesthetic integrity as well as long-term structural survival, to avoid otherwise inevitable disaster.

Bibliography


