WHY SHOULDN'T I REPLACE MY WINDOWS?

People constantly tell to me they need new windows because they fear lead paint, want better soundproofing, energy efficiency and easy cleaning. Then the answer is to restore original windows, not replace them.

Restoration costs less and the windows will be lead free, soundproof, energy efficient and easily cleaned. I've trained many small contractors and homeowners how to perform this task efficiently and cost effectively. For those who insist they want tilt-ins for easier cleaning, this system gives them an easy cleaning solution as well.

All of this and a new combination wood storm/screen or interior storm cost less than a wood tilt-in with vinyl jamb liners and no storm. This system keeps the sash weights, cuts nothing off the window sash and removes all old paint and glazing. My friend John Seekircher always says, "The reason they call them replacement windows is that you have to replace them over and over again,"

EPA & HUD lead paint regulations are out of control. The facts however fly in the face of this anti-preservation intrusion into our lives. Lead poisoning in children has been depicted by HUD and the EPA as an epidemic. The facts do not support this notion. Children today have less lead poisoning than ever before in history and it has little to do with lead paint regulations. Taking lead out of gasoline and better factory emissions are responsible for much of this.

In essence we should be teaching the uneducated, educated, poor and well-off families to clean their houses. Common sense education is all that's needed with lead paint. Lead paint is only a hazard if it's unstable. Removing lead paint from window jambs and sashes is a safe, quick and easy process if the homeowner or contractor knows how to do it. We must start immediately training small contractors & homeowners how to do this. Right now the contractors that are getting lead certified are gouging homeowner's pocketbooks because they can.

The reason homeowner's think they need to replace their windows is that the window industry spends tens of millions of dollars a year to convince them to buy their inferior products. It will take a consumer about 40+ years to get any payback from replacement windows with insulated glass and considering the following statements in the window industries trade periodical, Glass Magazine, the industry makes the case for restoration.

July 2001 Glass Magazine, By Editor, Charles Cumpstom, "The consumer's perception of glass is significantly different from the industry's. While some in the industry think a 15-year life is adequate, it is the rare homeowner who envisions replacing all his windows in 15 years."

Another article in 1995 in Glass Magazine by Ted Hart states, "Remember our industry, with rare exception, has chosen to hide the fact that insulating glass does have a life expectancy. It is a crime that with full knowledge and total capability to build a superior unit, most of the industry chooses to manufacture an inferior single-seal unit." **NOTE:** Single seal units are still the norm with an average seal life of 2 to 6 years.

As a side note to this, I am not a general contractor. I believe it is a conflict to teach people how to do these things out of one side of my mouth and then try to get their business out of the other. I do however buy endangered, residential historic properties and rehab them. This keeps me in the fray with the least conflict of interest. Outside of my own rehabs, my only professional purpose is to teach cost effective preservation methodology and neighborhood planning.

RESTORE & MAINTAIN WINDOWS
*****
DON'T REPLACE THEM

- New wood windows are made with new growth lumber that is not as strong or rot resistant as the old growth lumber in windows made before the 1950s.
- Insulated glass seals tend to fail in 2 to 6 years allowing condensation between the panes.
- Most insulated glass panels cannot be replaced once they fail. The entire window must be replaced.
- Primary window sashes were never intended to take a direct hit from the weather. In early years they had shutters then storms to protect them.
- Air infiltration is the biggest energy issue with windows. Vinyl windows, by their nature, have weep holes in their bottom rail to let the moisture seep out which allows massive air infiltration.
- PVC or vinyl is the most toxic consumer substance manufactured today. It can't be recycled, off gasses toxic fumes and has excessive contraction and expansion issues. It fades, cracks and has a maximum lifespan of 16 to 18 years.
- Metal clad windows are designed to allow water to seep behind the cladding. This causes early rot of the often finger jointed, new growth lumber underneath.
- The vinyl jamb liners that are needed for tilt-in windows have cheap spring balances and cheesy foam backing that have a lifespan of about 6 to 10 years.
- Double hung windows were invented in the 1400s as an air conditioning system. Lower the top sash and raise the lower sash. This lets the hot air and humidity out the top and brings the breezes in through the bottom. Most replacement units don't have a full screen to allow for this process.
- Aluminum, self-storing storm windows are not even a good windbreak. Metal conducts heat and cold while wood insulated against heat and cold.
- Sash weight pockets are only a problem if a house has not been caulked and painted properly.
- Quarter inch thick, laminated glass has better UV protection than all the low-e coatings. It also approaches the same thermal capabilities as insulated glass, is more soundproof, is safer and cost less than insulated glass. If retrofitting glass into an old sash is something you feel must be done, install laminated glass.
- Original window sash is a part of the footprint of your old house or building. Replacements often have different dimensions and sometimes the window contractor wants to reduce the size of your openings. This has a negative effect on the overall texture and look of the original footprint of your building.
- If you don't want to lift a finger to maintain or rehab your home then hire a contractor to restore your windows. Your restored windows will cost less, have a better payback, be easily cleaned, have a nice track system, and stop air infiltration, which means greater energy efficiency.

- Restored wood windows have another 100-year economic life before total restoration is needed again. Replacement windows can never be restored effectively.

Bob Yapp – Preservation Resources, Inc.

The recent events concerning the replacement of windows in an Owego building is not a simple matter of the health of a child versus the exterior appearance of historic landmark. This false debate hides the real issues from the public. The media should be presenting the larger story and its impact on public policy.

If removing older windows from a historic building is required for the health of a child, everyone, including historic preservationists, would support this action. In fact, it is not necessary, nor even the best solution. Exposure to lead can easily be eliminated by removing the old lead-base paint, covering it with readily available special paints or installing internal storm windows. Simply removing the old windows can be an inadequate solution and give owners a false sense of safety. Old buildings are often full of lead-base paint. If the rest of the building is ignored, removing the small of amount of paint found on window frames does not really solve the problem.

If the issue in Owego was only about the health of a child, there would be no public debate. The owners had other viable alternatives and were given advice by the Owego Historic District Commission (OHDC) on how to solve the problem. The real debate is over energy efficiency, convenience, cost and community versus individual property rights. Do the "advantages" of vinyl replacements outweigh the loss of historical integrity?

Many people think double-pane vinyl replacement windows are a smart investment and will significantly improve the energy efficiency of their home. There are also recent studies which show that it takes years to realize the savings and that there are more cost effective ways to improve the energy efficiency of older buildings. For more information see www.pastny.org/news_articles/index.htm.

Another selling point of replacement windows is convenience. You don't need to find someone to repair your old windows. For a single price some companies will measure, design, construct, acquire the necessary building permits and approval for historic district commissions, and install. All maintenance problems solved. As events in Owego demonstrate, however, such promises are not always fully realized. Historic district commissions generally do not think vinyl replacement window are appropriate for historic buildings despite claims made by the industry.

Some people find well designed replacement windows easier to clean or they like their appearance better than the old ones. This brings us to the larger issue, choice. If property owners prefer vinyl replacement windows for whatever reason, what right does local government have to them they can't install them? How can government restrict the sale and use of a legal product?

The answer is zoning. Zoning is an accepted part of public policy for all sorts of reasons. We use zoning and building codes to promote health, safety and economic development and to make our communities better places to live. Zoning by its very nature limits some property owners' rights for the common good of the community.

The real story in Owego is not about the child's health. That can be resolved without undermining the integrity of the district. The hidden agenda under the sensational story is the issue of zoning and whether the design guidelines of the historic district are appropriate and should be enforced.

The State of New York created the historic district to help preserve the historical integrity of this wonderful asset for citizens Owego, Tioga County and the entire state.

Most property owners in the district support the restrictions place on them because of the benefits that historic designation brings.

Others disagree. Some may feel that preserving the historic character of the district is not worth placing limits on property rights. Some companies, for example, may oppose limits to their potential markets. Removing restrictions on vinyl windows in historic districts would certainly strengthen the argument for convenience and promote their product as appropriate for all historic homes.

This argument, however, should be made openly in public debate. We should not let sensationalized stories over the health of a child be used to weaken public support for OHDC and set precedent for installing vinyl windows in historic districts. It is unfair and it is bad politics.

Dorbin Metal Strip Mfg. Co., Inc.

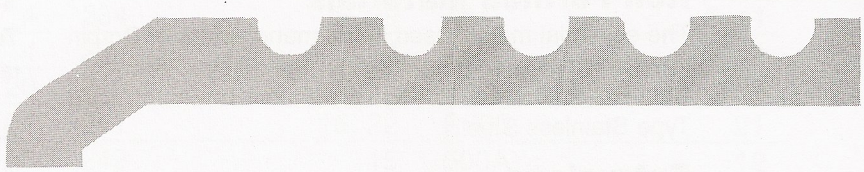
DORBIN

Thresholds

Weather Strips

Door Equipment

Window Equipment



Chicago Phone: **773-242-2333**

Cicero Phone: **708-656-2333**

Fax Number: **708-656-1333**

Double Hung Wood Windows — Full Size Details

Return Flange Equipment for Residential or Commercial Buildings

Zinc
Heads & Sills—Plain
1/8" rib x 7/16" high
3/8" flange (.018)

2P 1" wide
4P 1 3/8" wide
7P 1 3/4" wide
9P 2" wide
10P 2 1/4" wide

Zinc Meeting Rails

M1Z (.024) large hook
M2Z(.018) small hook

Alternate Zinc Meeting Rails

M3Z (.018) hemmed hook
M4Z (.018) double flat

Zinc
Upper & Lower
Sides—Corrugated
1/8" rib x 7/16" high
3/8" flange (.018)

300C 1 3/8" wide
302C 1 3/4" wide
303C 2" wide
304C 2 1/4" wide

Recommended Equipment in Zinc by Sash Thickness

1 3/8" Sash Thickness

Head—2P
Upper Side—300C
Meeting Rails—M1M2
Lower Side—302C
Sill—4P

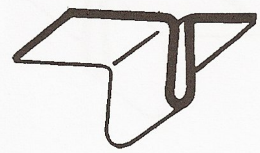
1 3/4" Sash Thickness

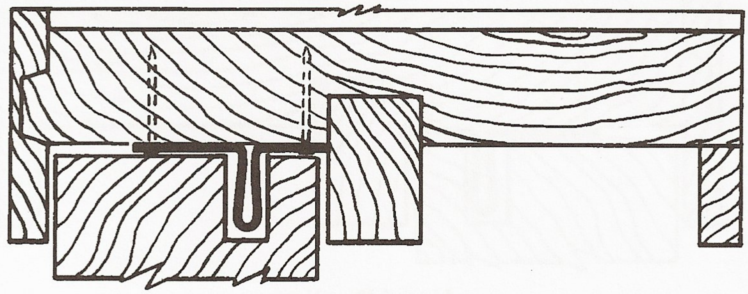
Head—2P
Upper Side—302C
Meeting Rails—M1M2
Lower Side—303C
Sill—7P

2" Sash Thickness

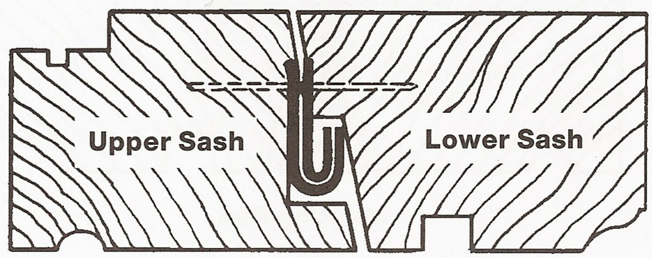
Head—4P
Upper Side—303C
Meeting Rails—M1M2
Lower Side—304C
Sill—9P

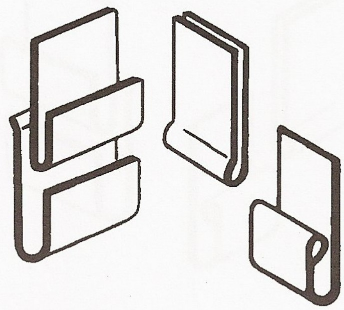
No. 10 Equipment



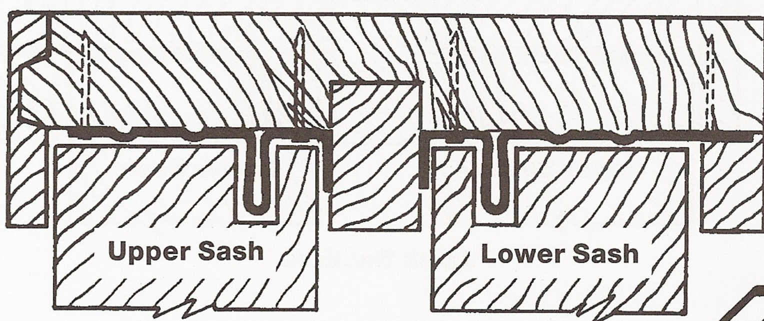


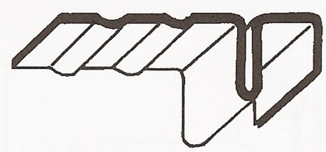
Head Section



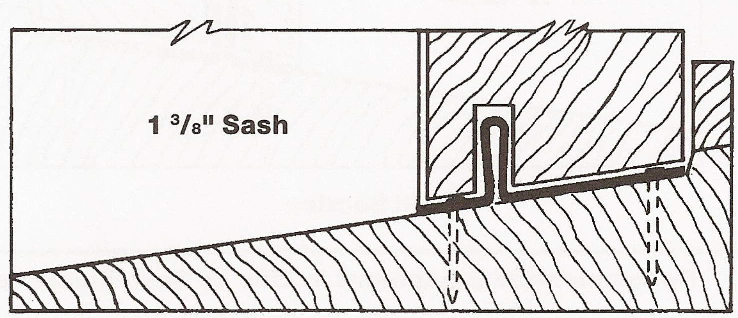


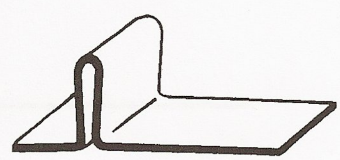
Meeting Rail





Jamb Section





Sill

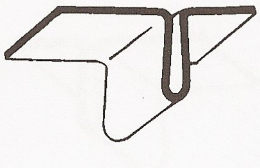
Available in Solid Bronze

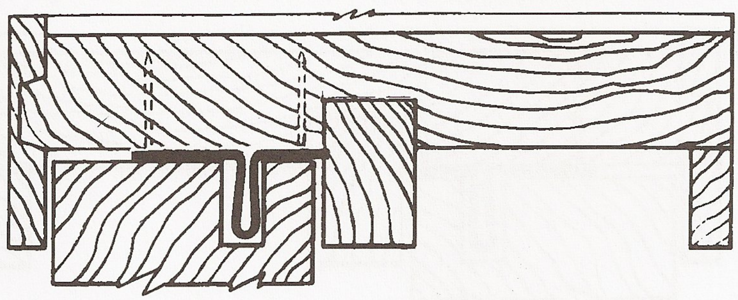
Double Hung Wood Windows

Standard Rib Strip for Residential or Commercial Buildings

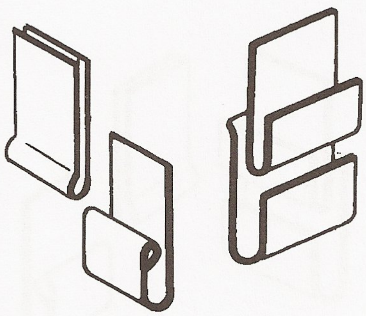
Full Size Details

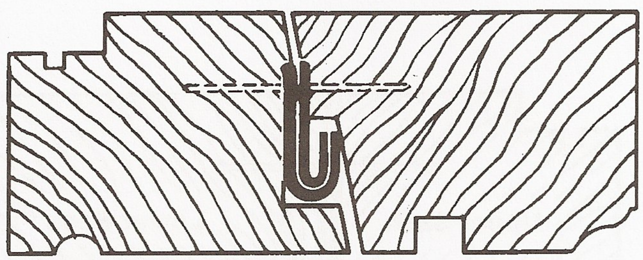
No. 5 Equipment



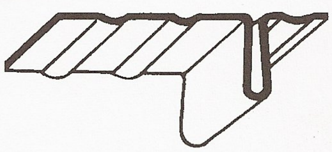


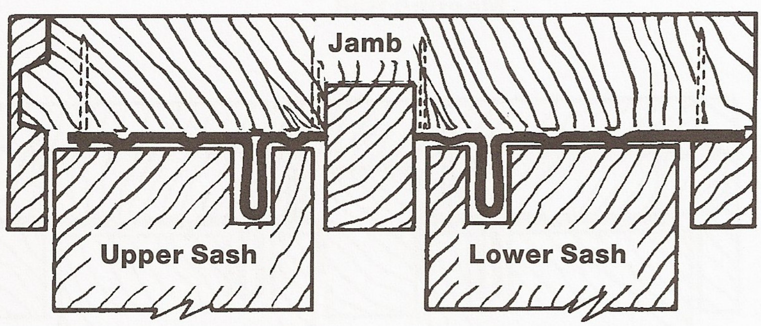
Head Section



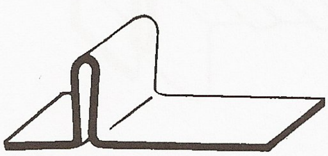


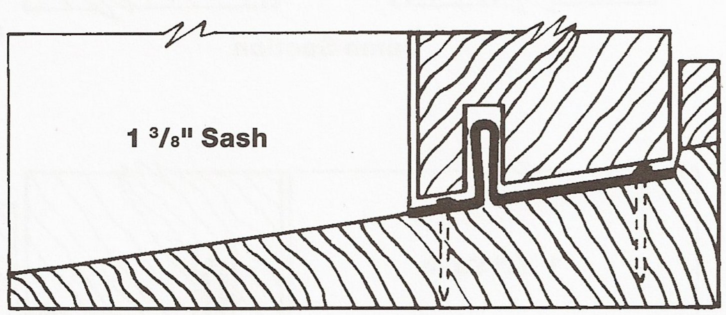
Meeting Rail





Jamb Section





Sill Section

Zinc
Heads & Sills—Plain
1/8" rib x 7/16" high
3/8" flange (.018)

2P 1" wide
4P 1 3/8" wide
7P 1 3/4" wide
9P 2" wide

Zinc Meeting Rails

M1Z (.024) large hook
M2Z(.018) small hook

Alternate Zinc Meeting Rails

M3Z (.018) hemmed hook
M4Z (.018) double flat

Zinc
Upper & Lower Sides—Corrugated
1/8" rib x 7/16" high
3/8" flange (.018)

4C 1 3/8" wide
7C 1 3/4" wide
9C 2" wide
10C 2 1/4" wide
11C 2 1/2" wide

Available in Solid Bronze

Recommended Equipment in Zinc by Sash Thickness

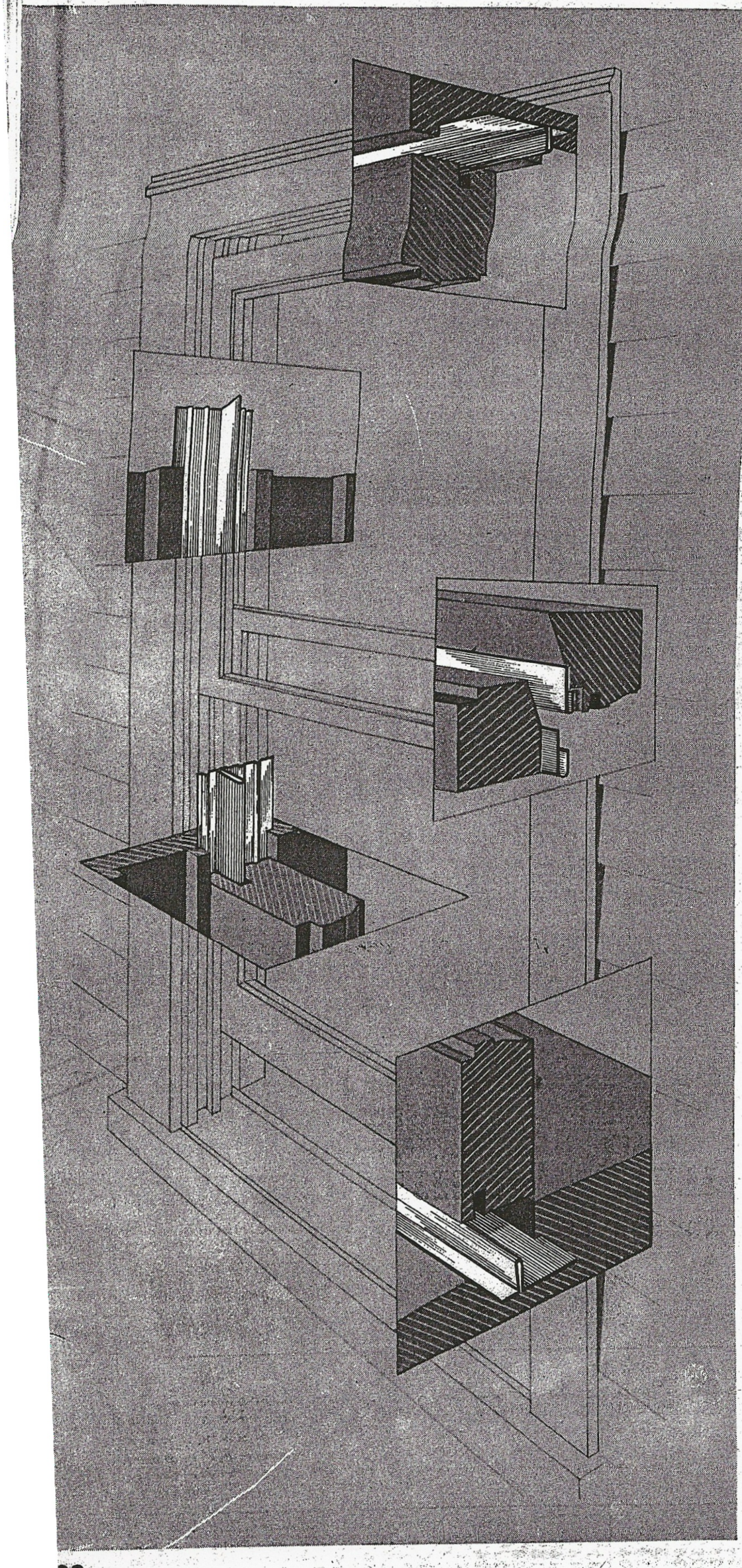
1 3/8" Sash Thickness
Head—2P
Upper Side—4C
Meeting Rails—M1M2
Lower Side—7C
Sill—4P

1 3/4" Sash Thickness
Head—2P
Upper Side—7C
Meeting Rails—M1M2
Lower Side—9C
Sill—7P

2" Sash Thickness
Head—4P
Upper Side—9C
Meeting Rails—M1M2
Lower Side—10C
Sill—9P

2 1/4" Sash Thickness
Head—4P
Upper Side—10C
Meeting Rails—M1M2
Lower Side—11C
Sill—10P

MASTER INTERLOCKING EQUIPMENT "A"



FOR DOUBLE-HUNG WOOD SASH

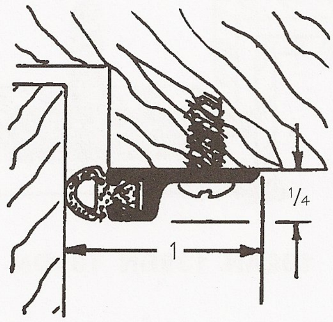
For residential work where the equipment is subject to only moderate use, Equipment "A" is ordinarily specified. Here, of course, the lower cost is also a factor of *importance.*

Strips are wide enough to cover full width of head, sill and pulley stiles. Height of rib strip is full 7/16", assuring positive contact regardless of sash shrinkage.

Sash grooves are 5/32" wide and 1/2" deep, allowing a clearance of 1/32". Where smaller clearance is wanted, the groove can be 9/64" wide. Experience has shown that these clearances permit maximum efficiency, yet are sufficient to allow the sash to operate smoothly even though the wood may warp. Lower side strips are usually kerfed 1/8" into the parting stop, but this is not ordinarily done on the upper sash. Meeting rail installation is optional and can also be installed as shown on page 17.

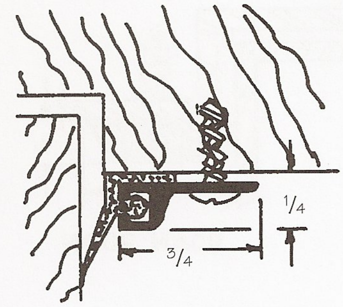
Head & Jamb Weatherstrips

Full Size Details

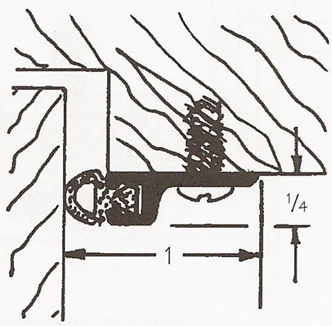


399S 399SD 399SG

EPDM Flexible at Low Temperatures



299AV 299DV 299GV



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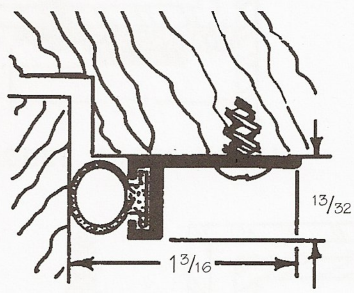

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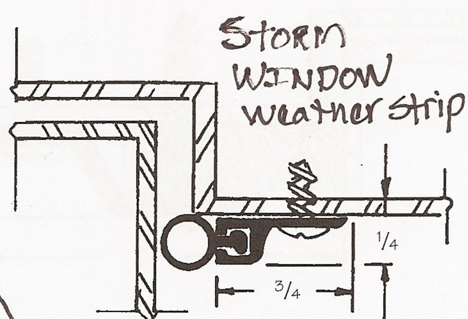

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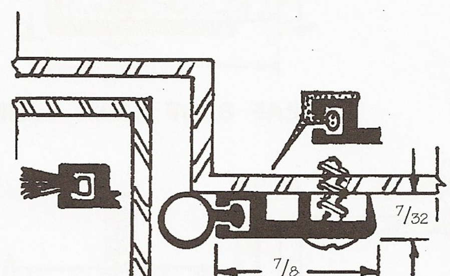
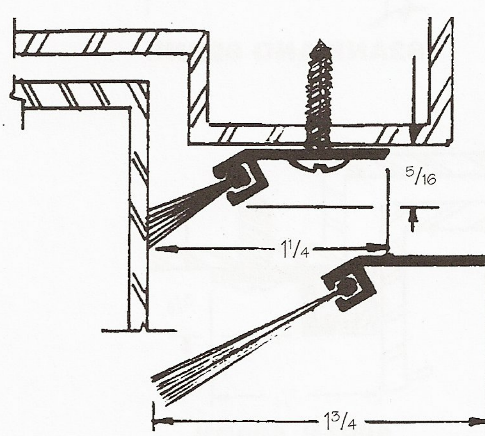
199AV 199DV 199GV

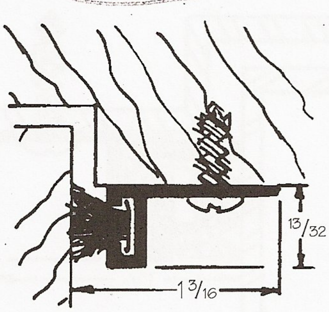


240AS 240AV 240AP
240DS 240DV 240DP



233AP
233DP

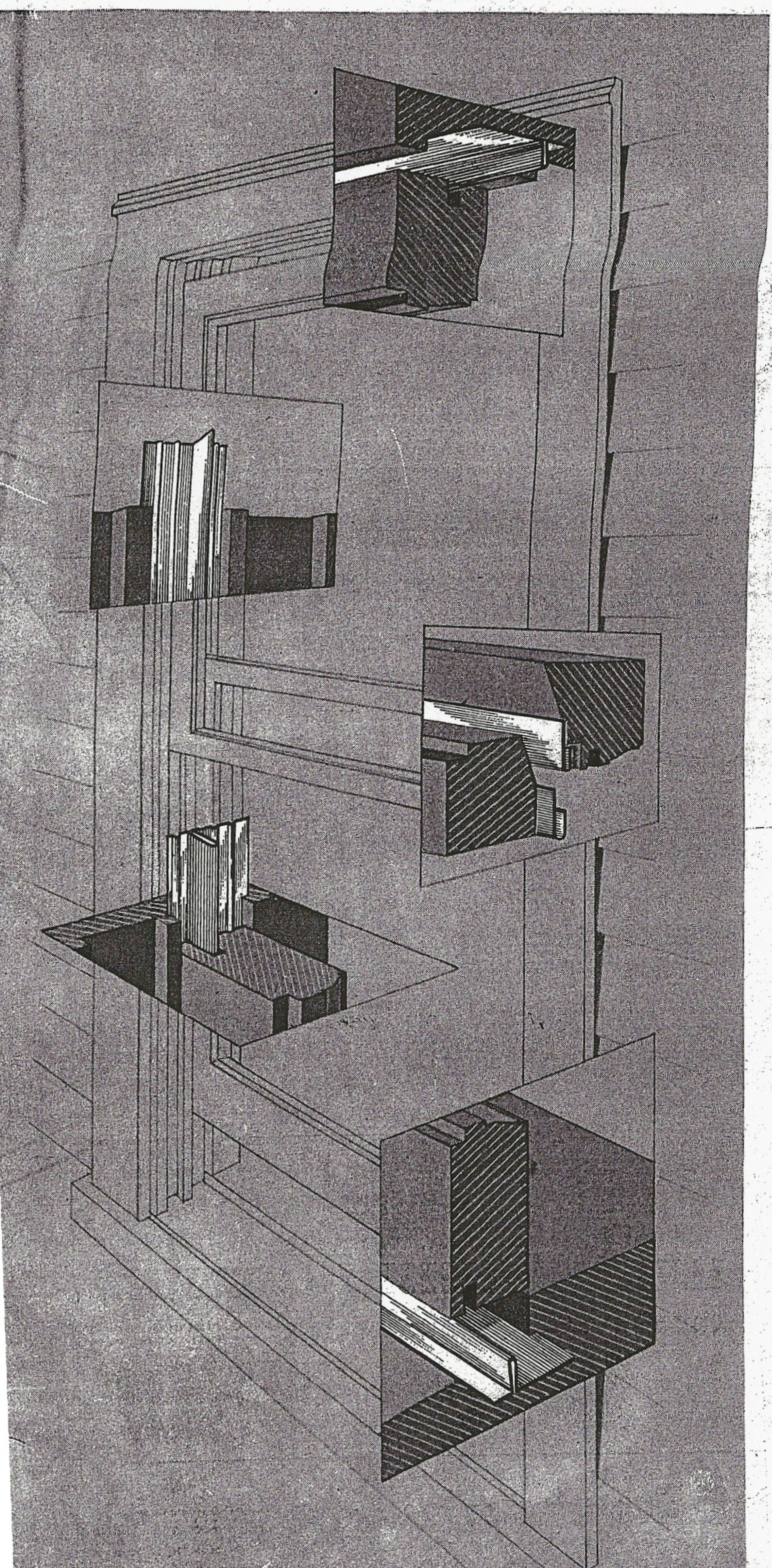
234AP
234DP



599AP 599DP

MATERIAL DESIGNATIONS

A	Aluminum	B	Bronze	BR	Brass	D	Dark Brown Anodized or Paint
S	Santoprene	F	Felt	G	Gold	N	Solid or Closed Cell Neoprene
P	Pile	SS	Stainless Steel	V	Vinyl	Z	Zinc



FOR DOUBLE-HUNG WOOD SASH

For residential work where the equipment is subject to only moderate use, Equipment "A" is ordinarily specified. Here, of course, the lower cost is also a factor of importance.

Strips are wide enough to cover full width of head, sill and pulley stiles. Height of rib strip is full 7/16", assuring positive contact regardless of sash shrinkage.

Sash grooves are 5/32" wide and 1/2" deep, allowing a clearance of 1/32". Where smaller clearance is wanted, the groove can be 9/64" wide. Experience has shown that these clearances permit maximum efficiency, yet are sufficient to allow the sash to operate smoothly even though the wood may warp. Lower side strips are usually kerfed 1/8" into the parting stop, but this is not ordinarily done on the upper sash. Meeting rail installation is optional and can also be installed as shown on page 17.

The Repair of Historic Wooden Windows

John H. Myers

A NOTE TO OUR USERS: The web versions of the **Preservation Briefs** differ somewhat from the printed versions. Many illustrations are new, captions are simplified, illustrations are typically in color rather than black and white, and some complex charts have been omitted.

The windows on many historic buildings are an important aspect of the architectural character of those buildings. Their design, craftsmanship, or other qualities may make them worthy of preservation. This is self-evident for ornamental windows, but it can be equally true for warehouses or factories where the windows may be the most dominant visual element of an otherwise plain building. Evaluating the significance of these windows and planning for their repair or replacement can be a complex process involving both objective and subjective considerations. *The Secretary of the Interior's Standards for Rehabilitation* and the accompanying guidelines, call for respecting the significance of original materials and features, repairing and retaining them wherever possible, and when necessary, replacing them in kind. This Brief is based on the issues of significance and repair which are implicit in the standards, but the primary emphasis is on the technical issues of planning for the repair of windows including evaluation of their physical condition, techniques of repair, and design considerations when replacement is necessary.

Much of the technical section presents repair techniques as an instructional guide for the do-it-yourselfer. The information will be useful, however, for the architect, contractor, or developer on large-scale projects. It presents a methodology for approaching the evaluation and repair of existing windows, and considerations for replacement, from which the professional can develop alternatives and specify appropriate materials and procedures.

Architectural or Historical Significance

Evaluating the architectural or historical significance of windows is the first step in planning for window treatments, and a general understanding of the function and history of windows is vital to making a proper evaluation. As a part of this evaluation, one must consider four basic window functions: admitting light to the interior spaces, providing fresh air and ventilation to the interior, providing a visual link to the outside world, and enhancing the appearance of a building. No single factor can be disregarded when planning window treatments; for example, attempting to conserve energy by closing up or reducing the size of window openings may result in the use of *more* energy by increasing electric lighting loads and decreasing passive solar heat gains.

Windows are frequently important visual focal points, especially on simple facades such as this mill building. Replacement of the multi-pane windows with larger panes could dramatically alter the appearance of the building. Photo: NPS files.

Historically, the first windows in early American houses were casement windows; that is, they were hinged at the side and opened outward. In the beginning of the eighteenth century single- and double-hung windows were introduced. Subsequently many styles of these vertical sliding sash windows have come to be associated with specific building periods or architectural styles, and this is an important consideration in determining the significance of windows, especially on a local or regional basis. Site-specific, regionally oriented architectural comparisons should be made to determine the significance of windows in question. Although such comparisons may focus on specific window types and their details, the ultimate determination of significance should be made within the context of the whole building, wherein the windows are one architectural element.

After all of the factors have been evaluated, **windows should be considered significant to a building if they: 1)** are original, **2)** reflect the original design intent for the building, **3)** reflect period or regional styles or building practices, **4)** reflect changes to the building resulting from major periods or events, or **5)** are examples of exceptional craftsmanship or design. Once this evaluation of significance has been completed, it is possible to proceed with planning appropriate treatments, beginning with an investigation of the physical condition of the windows.

Physical Evaluation

The key to successful planning for window treatments is a careful evaluation of existing physical conditions on a unit-by-unit basis. A graphic or photographic system may be devised to record existing conditions and illustrate the scope of any necessary repairs. Another effective tool is a window schedule which lists all of the parts of each window unit. Spaces by each part allow notes on existing conditions and repair instructions. When such a schedule is completed, it indicates the precise tasks to be performed in the repair of each unit and becomes a part of the specifications. In any evaluation, one should note at a minimum:

- **1)** window location
- **2)** condition of the paint
- **3)** condition of the frame and sill
- **4)** condition of the sash (rails, stiles and muntins)
- **5)** glazing problems
- **6)** hardware, and
- **7)** the overall condition of the window (excellent, fair, poor, and so forth)

Many factors such as poor design, moisture, vandalism, insect attack, and lack of maintenance can contribute to window deterioration, but moisture is the primary contributing factor in wooden window decay. All window units should be inspected to see if water is entering around the edges of the frame and, if so, the joints or seams should be caulked to eliminate this danger. The glazing putty should be checked for cracked, loose, or missing sections which allow water to saturate the wood, especially at the joints. The back putty on the interior side of the pane should also be inspected, because it creates a seal which prevents condensation from running down into the joinery. The sill should be examined to insure that it slopes downward away from the building and allows water to drain off. In addition, it may be advisable to cut a dripline along the underside of the sill. This almost invisible treatment will insure proper water runoff, particularly if the bottom of the sill is flat. Any conditions, including poor original design, which permit water to come in contact with the wood or to puddle on the sill must be corrected as they contribute to deterioration of the window.

One clue to the location of areas of excessive moisture is the condition of the paint; therefore, each window should be examined for areas of paint failure. Since excessive moisture is detrimental to the paint bond, areas of paint blistering, cracking, flaking, and peeling usually identify points of water penetration, moisture saturation, and potential deterioration. Failure of the paint should not, however, be mistakenly interpreted as a sign that the wood is in poor condition and hence, irreparable. Wood is frequently in sound physical condition beneath unsightly paint. After noting areas of paint failure, the next step is to inspect the condition of the wood, particularly at the points identified during the paint examination.

Deterioration of poorly maintained windows usually begins on horizontal surfaces and at joints, where water can collect and saturate the wood. Photo: NPS files.

Each window should be examined for operational soundness beginning with the lower portions of the frame and sash. Exterior rainwater and interior condensation can flow downward along the window, entering and collecting at points where the flow is blocked. The sill, joints between the sill and jamb, corners of the bottom rails and muntin joints are typical points where water collects and deterioration begins. The operation of the window (continuous opening and closing over the years and seasonal temperature changes) weakens the joints, causing movement and slight separation. This process makes the joints more vulnerable to water which is readily absorbed into the endgrain of the wood. If severe deterioration exists in these areas, it will usually be apparent on visual inspection, but other less severely deteriorated areas of the wood may be tested by two traditional methods using a small ice pick.

An ice pick or an awl may be used to test wood for soundness. The technique is simply to jab the pick into a wetted wood surface at an angle and pry up a small section of the wood. Sound wood will separate in long fibrous splinters, but decayed wood will lift up in short irregular pieces due to the breakdown of fiber strength.

Another method of testing for soundness consists of pushing a sharp object into the wood, perpendicular to the surface. If deterioration has begun from the hidden side of a member and the core is badly decayed, the visible surface may appear to be sound wood. Pressure on the probe can force it through an apparently sound skin to penetrate deeply into decayed wood. This technique is especially useful for checking sills where visual access to the underside is restricted.

Following the inspection and analysis of the results, the scope of the necessary repairs will be evident and a plan for the rehabilitation can be formulated. Generally the actions necessary to return a window to "like new" condition will fall into three broad categories: ***1) routine maintenance procedures***, ***2) structural stabilization***, and ***3) parts replacement***. These categories will be discussed in the following sections and will be referred to respectively as **Repair Class I**, **Repair Class II**, and **Repair Class III.** Each successive repair class represents an increasing level of difficulty, expense, and work time. Note that most of the points mentioned in Repair Class I are routine maintenance items and should be provided in a regular maintenance program for any building. The neglect of these routine items can contribute to many common window problems.

Before undertaking any of the repairs mentioned in the following sections all sources of moisture penetration should be identified and eliminated, and all existing decay fungi destroyed in order to arrest the deterioration process. Many commercially available fungicides and wood preservatives are toxic, so it is extremely important to follow the manufacturer's recommendations for application, and store all chemical materials away from children and animals. After fungicidal and preservative treatment the windows may be stabilized, retained, and restored with every expectation for a long service life.

Repair Class I: Routine Maintenance

Repairs to wooden windows are usually labor intensive and relatively uncomplicated. On small scale projects this allows the do-it-yourselfer to save money by repairing all or part of the windows. On larger projects it presents the opportunity for time and money which might otherwise be spent on the removal and replacement of existing windows, to be spent on repairs, subsequently saving all or part of the material cost of new window units. Regardless of the actual costs, or who performs the work, the evaluation process described earlier will provide the knowledge from which to specify an appropriate work program, establish the work element priorities, and identify the level of skill needed by the labor force.

This historic double-hung window has many layers of paint, some cracked and missing putty, slight separation at the joints, broken sash cords, and one cracked pane. Photo: NPS files.

After removing paint from the seam between the interior stop and the jamb, the stop can be pried out and gradually worked loose using a pair of putty knives as shown. Photo: NPS files.

The routine maintenance required to upgrade a window to "like new" condition normally includes the following steps: 1) some degree of interior and exterior paint removal, 2) removal and repair of sash (including reglazing where necessary), 3) repairs to the frame, 4) weatherstripping and reinstallation of the sash, and 5) repainting. These operations are illustrated for a typical double-hung wooden window, but they may be adapted to other window types and styles as applicable.

Historic windows have usually acquired many layers of paint over time. Removal of excess layers or peeling and flaking paint will facilitate operation of the window and restore the clarity of the original detailing. Some degree of paint removal is also necessary as a first step in the proper surface preparation for subsequent refinishing (if paint color analysis is desired, it should be conducted prior to the onset of the paint removal). There are several safe and effective techniques for removing paint from wood, depending on the amount of paint to be removed.

Paint removal should begin on the interior frames, being careful to remove the paint from the interior stop and the parting bead, particularly along the seam where these stops meet the jamb. This can be accomplished by running a utility knife along the length of the seam, breaking the paint bond. It will then be much easier to remove the stop, the parting bead and the sash. The interior stop may be initially loosened from the sash side to avoid visible scarring of the wood and then gradually pried loose using a pair of putty knives, working up and down the stop in small increments. With the stop removed, the lower or interior sash may be withdrawn. The sash

Sash can be removed and repaired in a convenient work area. Paint is being removed from this sash with a hot air gun. Photo: NPS files.

cords should be detached from the sides of the sash and their ends may be pinned with a nail or tied in a knot to prevent them from falling into the weight pocket.

Removal of the upper sash on double-hung units is similar but the parting bead which holds it in place is set into a groove in the center of the stile and is thinner and more delicate than the interior stop. After removing any paint along the seam, the parting bead should be carefully pried out and worked free in the same manner as the interior stop. The upper sash can be removed in the same manner as the lower one and both sash taken to a convenient work area (in order to remove the sash the interior stop and parting bead need only be removed from one side of the window). Window openings can be covered with polyethylene sheets or plywood sheathing while the sash are out for repair.

The sash can be stripped of paint using appropriate techniques, but if any heat treatment is used, the glass should be removed or protected from the sudden temperature change which can cause breakage. An overlay of aluminum foil on gypsum board or asbestos can protect the glass from such rapid temperature change. It is important to protect the glass because it may be historic and often adds character to the window. Deteriorated putty should be removed manually, taking care not to damage the wood along the rabbet. If the glass is to be removed, the glazing points which hold the glass in place can be extracted and the panes numbered and removed for cleaning and reuse in the same openings. With the glass panes out, the remaining putty can be removed and the sash can be sanded, patched, and primed with a preservative primer. Hardened putty in the rabbets may be softened by heating with a soldering iron at the point of removal. Putty remaining on the glass may be softened by soaking the panes in linseed oil, and then removed with less risk of breaking the glass. Before reinstalling the glass, a bead of glazing compound or linseed oil putty should be laid around the rabbet to cushion and seal the glass. Glazing compound should only be used on wood which has been brushed with linseed oil and primed with an oil based primer or paint. The pane is then pressed into place and the glazing points are pushed into the wood around the perimeter of the pane.

The final glazing compound or putty is applied and beveled to complete the seal. The sash can be refinished as desired on the inside and painted on the outside as soon as a "skin" has formed on the putty, usually in 2 or 3 days. Exterior paint should cover the beveled glazing compound or putty and lap over onto the glass slightly to complete a weather-tight seal. After the proper curing times have elapsed for paint and putty, the sash will be ready for reinstallation.

While the sash are out of the frame, the condition of the wood in the jamb and sill can be evaluated. Repair and refinishing of the frame may proceed concurrently with repairs to the sash, taking advantage of the curing times for the paints and putty used on the sash. One of the most common work items is the replacement of the sash cords with new rope cords or with chains. The weight pocket is frequently accessible through a door on the face of the frame near the sill, but if no door exists, the trim on the interior face may be removed for access. Sash weights may be increased for easier window operation by elderly or handicapped persons. Additional repairs to the frame and sash may include consolidation or replacement of deteriorated wood. Techniques for these repairs are discussed in the following sections.


Following the relatively simple repairs, the window is weathertight, like new in appearance, and serviceable for many years to come.Photo: NPS files.

The operations just discussed summarize the efforts necessary to restore a window with minor deterioration to "like new" condition. The techniques can be applied by an unskilled person with minimal training and experience. To demonstrate the practicality of this approach, and photograph it, a Technical Preservation Services staff member repaired a wooden double-hung, two over two window which had been in service over ninety years. The wood was structurally sound but the window had one broken pane, many layers of paint, broken sash cords and inadequate, worn-out weatherstripping. The staff member found that the frame could be stripped of paint and the sash removed quite easily. Paint, putty and glass removal required about one hour for each sash, and the reglazing of both sash was accomplished in about one hour. Weatherstripping of the sash and frame, replacement of the sash cords and reinstallation of the sash, parting bead, and stop required an hour and a half. These times refer only to individual operations; the entire process took several days due to the drying and curing times for putty, primer, and paint, however, work on other window units could have been in progress during these lag times.

Repair Class II: Stabilization

The preceding description of a window repair job focused on a unit which was operationally sound. Many windows will show some additional degree of physical deterioration, especially in the vulnerable areas mentioned earlier, but even badly damaged windows can be repaired using simple processes. Partially decayed wood can be waterproofed, patched, built-up, or consolidated and then painted to achieve a sound condition, good appearance, and greatly extended life. Three techniques for repairing partially decayed or weathered wood are discussed in this section, and all three can be accomplished using products available at most hardware stores.

One established technique for repairing wood which is split, checked or shows signs of rot, is to: **1)** dry the wood, **2)** treat decayed areas with a fungicide, **3)** waterproof with two or three applications of boiled linseed oil (applications every 24 hours), **4)** fill cracks and holes with putty, and **5)** after a "skin" forms on the putty, paint the surface. Care should be taken with the use of fungicide which is toxic. Follow the manufacturers' directions and use only on areas which will be painted. When using any technique of building up or patching a flat surface, the finished surface should be sloped slightly to carry water away from the window and not allow it to puddle. Caulking of the joints between the sill and the jamb will help reduce further water penetration.

This illustrates a two-part expoxy patching compound used to fill the surface of a weathered sill and rebuild the missing edge. When the epoxy cures, it can be sanded smooth and painted to achieve a durable and waterproof repair. Photo: NPS files.

When sills or other members exhibit surface weathering they may also be built-up using wood putties or homemade mixtures such as sawdust and resorcinol glue, or whiting and varnish. These mixtures can be built up in successive layers, then sanded, primed, and painted. The same caution about proper slope for flat surfaces applies to this technique.

Wood may also be strengthened and stabilized by consolidation, using semirigid epoxies which saturate the porous decayed wood and then harden. The surface of the consolidated wood can then be filled with a semirigid epoxy patching compound, sanded and painted. Epoxy patching compounds can be used to build up missing sections or decayed ends of members. Profiles can be duplicated using hand molds, which are created by pressing a ball of patching compound over a sound section of the profile which has been rubbed with butcher's wax. This can be a very efficient technique where there are many typical repairs to be done. The process has been widely used and proven in marine applications; and proprietary products are available at hardware and marine supply stores. Although epoxy materials may be comparatively expensive, they hold the promise of being among the most durable and long lasting materials available for wood repair. More information on epoxies can be found in the publication "Epoxies for Wood Repairs in Historic Buildings," cited in the bibliography.

Any of the three techniques discussed can stabilize and restore the appearance of the window unit. There are times, however, when the degree of deterioration is so advanced that stabilization is impractical, and the only way to retain some of the original fabric is to replace damaged parts.

Repair Class III: Splices and Parts Replacement

When parts of the frame or sash are so badly deteriorated that they cannot be stabilized there are methods which permit the retention of some of the existing or original fabric. These methods involve replacing the deteriorated parts with new matching pieces, or splicing new wood into existing members. The techniques require more skill and are more expensive than any of the previously discussed alternatives. It is necessary to remove the sash and/or the affected parts of the frame and have a carpenter or woodworking mill reproduce the damaged or missing parts. Most millwork firms can duplicate parts, such as muntins, bottom rails, or sills, which can then be incorporated into the existing window, but it may be necessary to shop around because there are several factors controlling the practicality of this approach. Some woodworking mills do not like to repair old sash because nails or other foreign objects in the sash can damage expensive knives (which cost far more than their profits on small repair jobs); others do not have cutting knives to duplicate muntin profiles. Some firms prefer to concentrate on larger jobs with more profit potential, and some may not have a craftsman who can duplicate the parts. A little searching should locate a firm which will do the job, and at a reasonable price. If such a firm does not exist locally, there are firms which undertake this kind of repair and ship nationwide. It is possible, however, for the advanced do-it-yourselfer or craftsman with a table saw to duplicate moulding profiles using techniques discussed by Gordie Whittington in "Simplified Methods for Reproducing Wood Mouldings," *Bulletin* of the Association for Preservation Technology, Vol. III, No. 4, 1971, or illustrated more recently in *The Old House*, Time-Life Books, Alexandria, Virginia, 1979.

The repairs discussed in this section involve window frames which may be in very deteriorated condition, possibly requiring removal; therefore, caution is in order. The actual construction of wooden window frames and sash is not complicated. Pegged mortise and tenon units can be disassembled easily, if the units are out of the building. The installation or connection of some frames to the surrounding structure, especially masonry walls, can complicate the work immeasurably, and may even require dismantling of the wall. It may be useful, therefore, to take the following approach to frame repair: **1)** conduct regular maintenance of sound frames to achieve the longest life possible, **2)** make necessary repairs in place, wherever possible, using stabilization and splicing techniques, and **3)** if removal is necessary, thoroughly investigate the structural detailing and seek appropriate professional consultation.

Another alternative may be considered if parts replacement is required, and that is sash replacement. If extensive replacement of parts is necessary and the job becomes prohibitively expensive it may be more practical to purchase new sash which can be installed into the existing frames. Such sash are available as exact custom reproductions, reasonable facsimiles (custom windows with similar profiles), and contemporary wooden sash which are similar in appearance. There are companies which still manufacture high quality wooden sash which would duplicate most historic sash. A few calls to local building suppliers may provide a source of appropriate replacement sash, but if not, check with local historical associations, the state historic preservation office, or preservation related magazines and supply catalogs for information.

If a rehabilitation project has a large number of windows such as a commercial building or an industrial complex, there may be less of a problem arriving at a solution. Once the evaluation of the windows is completed and the scope of the work is known, there may be a potential economy of scale. Woodworking mills may be interested in the work from a large project; new sash in volume may be considerably less expensive per unit; crews can be assembled and trained on site to perform all of the window repairs; and a few extensive repairs can be absorbed (without undue burden) into the total budget for a large number of sound windows. While it may be expensive for the average historic home owner to pay seventy dollars or more for a mill to grind a custom knife to duplicate four or five bad muntins, that cost becomes negligible on large commercial projects which may have several hundred windows.

Most windows should not require the extensive repairs discussed in this section. The ones which do are usually in buildings which have been abandoned for long periods or have totally lacked maintenance for years. It is necessary to thoroughly investigate the alternatives for windows which do require extensive repairs to arrive at a solution which retains historic significance and is also economically feasible. Even for projects requiring repairs identified in this section, if the percentage of parts replacement per window is low, or the number of windows requiring repair is small, repair can still be a cost effective solution.

Weatherization

A window which is repaired should be made as energy efficient as possible by the use of appropriate weatherstripping to reduce air infiltration. A wide variety of products are available to assist in this task. Felt may be fastened to the top, bottom, and meeting rails, but may have the disadvantage of absorbing and holding moisture, particularly at the bottom rail. Rolled vinyl strips may also be tacked into place in appropriate locations to reduce infiltration. Metal strips or new plastic spring strips may be used on the rails and, if space permits, in the channels between the sash and jamb. Weatherstripping is a historic treatment, but old weatherstripping (felt) is not likely to perform very satisfactorily. Appropriate contemporary weatherstripping should be considered an integral part of the repair process for windows. The use of sash locks installed on the meeting rail will insure that the sash are kept tightly closed so that the weatherstripping will function more effectively to reduce infiltration. Although such locks will not always be historically accurate, they will usually be viewed as an acceptable contemporary modification in the interest of improved thermal performance.

Many styles of storm windows are available to improve the thermal performance of existing windows. The use of exterior storm windows should be investigated whenever feasible because they are thermally efficient, cost-effective, reversible, and allow the retention of original windows (see "Preservation Briefs: 3"). Storm window frames may be made of wood, aluminum, vinyl, or plastic; however, the use of unfinished aluminum storms should be avoided. The visual impact of storms may be minimized by selecting colors which match existing trim color. Arched top storms are available for windows with special shapes. Although interior storm windows appear to offer an attractive option for achieving double glazing with minimal visual impact, the potential for damaging condensation problems must be addressed. Moisture which becomes trapped between the layers of glazing can condense on the colder, outer prime window, potentially leading to deterioration. The correct approach to using interior storms is to create a seal on the interior storm while allowing some ventilation around the prime window. In actual practice, the creation of such a durable, airtight seal is difficult.

Window Replacement

Although the retention of original or existing windows is always desirable and this Brief is intended to encourage that goal, there is a point when the condition of a window may clearly indicate replacement. The decision process for selecting replacement windows should not begin with a survey of contemporary window products which are available as replacements, but should begin with a look at the windows which are being replaced. Attempt to understand the contribution of the window(s) to the appearance of the facade including: **1)** the pattern of the openings and their size; **2)** proportions of the frame and sash; **3)** configuration of window panes; **4)** muntin profiles; **5)** type of wood; **6)** paint color; **7)** characteristics of the glass; and **8)** associated details such as arched tops, hoods, or other decorative elements. Develop an understanding of how the window reflects the period, style, or regional characteristics of the building, or represents technological development.

Armed with an awareness of the significance of the existing window, begin to search for a replacement which retains as much of the character of the historic window as possible. There are many sources of suitable new windows. Continue looking until an acceptable replacement can be found. Check building supply firms, local woodworking mills, carpenters, preservation oriented magazines, or catalogs or suppliers of old building materials, for product information. Local historical associations and state historic preservation offices may be good sources of information on products which have been used successfully in preservation projects.

Consider energy efficiency as one of the factors for replacements, but do not let it dominate the issue. Energy conservation is no excuse for the wholesale destruction of historic windows which can be made thermally efficient by historically and aesthetically acceptable means. In fact, a historic wooden window with a high quality storm window added should thermally outperform a new double-glazed metal window which does not have thermal breaks (insulation between the inner and outer frames intended to break the path of heat flow). This occurs because the wood has far better insulating value than the metal, and in addition many historic windows have high ratios of wood to glass, thus reducing the area of highest heat transfer. One measure of heat transfer is the U-value, the number of Btu's per hour transferred through a square foot of material. When comparing thermal performance, the lower the U-value the better the performance. According to ASHRAE 1977 Fundamentals, the U-values for single glazed wooden windows range from 0.88 to 0.99. The addition of a storm window should reduce these figures to a range of 0.44 to 0.49. A non-thermal break, double-glazed metal window has a U-value of about 0.6.

Conclusion

Technical Preservation Services recommends the retention and repair of original windows whenever possible. We believe that the repair and weatherization of existing wooden windows is more practical than most people realize, and that many windows are unfortunately replaced because of a lack of awareness of techniques for evaluation, repair, and weatherization. Wooden windows which are repaired and properly maintained will have greatly extended service lives while contributing to the historic character of the building. Thus, an important element of a building's significance will have been preserved for the future.

Additional Reading

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Home page logo: Historic six-over-six windows--preserved. Photo: NPS files.

This publication has been prepared pursuant to the National Historic Preservation Act of 1966, as amended, which directs the Secretary of the Interior to develop and make available information concerning historic properties. Technical Preservation Services (TPS), Heritage Preservation Services Division, National Park Service prepares standards, guidelines, and other educational materials on responsible historic preservation treatments for a broad public.

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SASH & JAMB RESTORATION SPECIFICATIONS

Work Description

A) Sash Removal and Restoration.

A-1) Be sure window opening to be worked on has a weather stripped storm window in place to protect the house from the weather. If not protect with ½" OSB board

A-2) Remove all interior sash stop, parting stop, metal weather stripping & both window sashes from the opening and mark for location that can survive paint removal. Discard parting stop and keep interior stop. If new interior stop is to be installed, discard original interior stop. Save all screw and washers removed from interior stop for later re-use.

A-3) Remove sash cords from sash weights & leave weights in jamb pocket.

A-4) Carefully remove sash pulleys from jamb & all hardware. Safely store all hardware & screws.

A-5) Remove all paint, putty & non-original obstructions from the 4 surfaces of the wood jambs, all surfaces of the window sashes and the interior stop. DO NOT dry scrape jambs, stops or sashes. All paint removal from sashes and interior stops must either take place off-site or in an area on the subject property, outside the main house. Use a wet paint removal product or mist the jambs with water before carbide scraping the jambs. Do not use heat that exceeds 600 degrees to remove paint. Over 600 degrees causes lead paint fumes that are toxic and can burn the original wood. Dispose of all paint debris according to local regulations.

A-6) Remove all remnants of glazing putty and glass. If the glass is of no historical importance, break it out, our over a large garbage can. This should remove most of the glazing putty as the glass is broken. If the glass is of historical importance attempted to save as much original glass as possible for re-installation later. The average glass loss under this scenario is about 20%.

A-7) Repair individual window sashes, as needed. Clamp and re-pin sagging rails and stiles & utilize architectural epoxies. If rotted wood exists on the interior side of a sash and it will be finished naturally, it should have new wood that matches the original spliced in. If a sash is disassembled, **DO NOT** glue-up the mortise and tenon joints when re-assembling. Pinning the joints with two, a hot-dipped, galvanized finish nails that have been cut off shorter than the thickness of the sash and driven into the mortise and tenon joint, at opposing angles, if sufficient as long as the joint is clamped snuggly before pinning. Provide new parting and interior stop as needed to closely match originals.

A-8) Repair jambs as needed with wood or exterior architectural epoxies. If the jamb is to be natural, use exterior grade fillers that will take a stain.

A-9) Lightly sand to 120 grit, all wood jambs, sills, interior stops & window sashes. Prime the faces, top& bottom edges of the window sashes only and do not prime or paint the sides of the sash. Prime all, including the glazing bed with alkyd oil based primer. **See Specification #109 for priming requirements.**

A-10) Install all original & new glass into bed of acrylic-latex, siliconized caulking & secure with adequate glazing points. All new glass is to be double strength. Install new glazing putty so that putty, at glass, is in the same sight plane as interior molding edge of sash. The glazing putty that is to be used is Glazol by UGL. This professional grade putty skins over quickly and can be primed and painted within 24 hours of installation.

A-11) Prime glazing putty with alkyd, oil based primer. **See Specification #109 for priming requirements.**

A-12) Apply two topcoats of the Acrylic Latex paint to sashes, jambs & sills. **Specification #109 for priming requirements.**
A-13) Stain, if needed, and apply three coats of White or Amber Shellac to interior sash surface, interior stop and parting stop to match original woodwork finish for that room.

B) Install Restored Sash.

B-1) Make all sash pulleys functional. If any are missing replace with new or salvaged pulleys that match in size & shape. Clean the surface of the pulleys, sash lifts & interior stop screws/washers without removing patina, do not buff unless you can establish that the original finish was polished. If any interior stop screws/washers are missing, provide new ones that are aged to match original patina.

B-2) Install sash pulleys with original or new, aged screws.

B-3) Install upper sashes with original or new metal weather stripping By Dorbin Metal Strip Company (see attached supplier list) & new parting stop. Parting stop to be attached with 3 brass screws that are counter sunk instead of nailed. This makes it easier to pull the top sash for cleaning the exterior side of the glass. Install the bottom sash in the same manner.

B-4) Install all sashes use nylon sash cord.

B-5) Install refinished interior sash stop with original screws and washers.

B-6) Clean up the area and dispose of all debris off-site.

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WINDOW & STORM PAINTING SPECIFICATIONS

Work Description

A) Preparation

A-1) Remove all paint from sashes, jambs, sills and interior stools. Remove the paint with either liquid strippers or infrared heat and carbide hand scrapers. DO NOT DRY SCRAPE. Always mist the paint with water before carbide scraping. Do not excessively heat the wood or it will produce lead fumes over 600 degrees or scorch the wood. If using a standard heat gun, it is not necessary to heat the paint very long. After lightly heating the paint go to another sash or jamb. This allows the heated paint to cool down making removal of the water misted paint easier. Stage the paint removal, except jambs/sills/stools either off-site or outside the building, on the grounds. Before scraping, all areas on the ground must be tarped off and all windows must be closed. Dispose of all paint debris according to local regulations. Always wear a double filtered respirator rated for lead fumes as well as safety glasses.

B) Wood Repairs

B-1) Repair any rotted broken or cracked siding and trim with like material and/or architectural epoxies. All epoxy wood repairs to be made with both LiquidWood & WoodEpox by ABATRON 262-653-2000 or www.abatron.com.

C) Hand Washing

C-1) All bare wood should be hand washed with TSP and water. Use ¼ cup of TSP for every gallon of water and scrub the siding. This should then be rinsed with a hose without a spray nozzle.

D) Moisture

D-1) Before any primer or paint is applied on the wood, you must test the wood to be sure the moisture content does not exceed 15%. The only way to determine this is with a moisture meter. All house painters should have one of these meters. Painting wood above 15% moisture can knock 5 to ten years off the life of the paint job. Power washing is an automatic prescription for paint failure and is not allowed. The high pressure drives moisture deep into the wood and it can take as long as six months to dry down to 15% moisture.

E) Priming

E-1) Prime all bare wood surfaces only with Benjamin Moore "Moorwhite" exterior alkyd oil primer. Latex primer does not bite into the wood and condition it properly for caulk and topcoats. This should be applied by brush, not spray. Cover all areas not to receive paint to assure no dripping or spilling on these surfaces.

F) Caulking

F-1) Use a paintable, acrylic/latex caulk with silicon. Imagine your house under Niagara Falls. Caulk all areas the cascading water can penetrate, but don't caulk where it can't.

G) Two Top Coats

G-1) Brush-on two coats of Benjamin Moore, MoorGlo semi-gloss, acrylic latex as topcoats to all wood surfaces. Color determined by owner.

H) Paint Maintenance

H-1) A paint job must be maintained on a yearly basis. Look around the house to see if any paint is failing. Paint failure, on a properly painted house, can be caused by things such as exhaust fans not sealed properly, leaky gutters or roof problems. Correct the moisture problems first, then scrape, prime and paint the failed areas.

STORM WINDOW SPECIFICATIONS

<u>Work Description</u>

A) Replacing & Installing Wood Storm Windows

A-1) Remove all aluminum storm windows and dispose of according to owner's recommendation.

A-2) Measure Storm window opening for sill angle and horizontal dividing rail position. Measure horizontal diving rail from top of jamb to center of sash meeting rails. New Storm measurement should have no more that a 1/8" reveal on the top & two sides. A gap of no less than 1/8" and no more than 3/16"must be provided between bottom rail of storm & sill of window.

A-3) Order all Storms from Marvin Windows Manufacturing. Order their "Wood Combination Window" factory primed. These are self-storing wood storm windows.

A-4) Fit, trim and install all new wood storms after all exterior window opening and trim is painted.. Attach storms using stainless steel flat head screws over stainless steel, decorative cup washers. Three screws for each stile with the center screw located on the stile at the center horizontal rail. Maintain a 1/8" reveal on the top & two sides. A gap of no less than 1/8" and no more than 3/16"must be provided between bottom rail of storm & sill of window.

A-5) Weather-strip only the top and both sides of all storms with weather stripping #199DV by Dorbin Metal Strip Manufacturing Company, Inc. 773-242-2333. They also have a catalogue you can order. Do not weather strip the bottom rail of any storms.

A-6) Brush two coats of Benjamin Moore, MoorGlo semi-gloss acrylic latex as topcoats to all surfaces of factory-primed storms. Color determined by owner. **See #101**

The Vinyl Lie

By Gary Kleier

Every day unsuspecting owners of historic homes, believing they are actually making an investment in their home, succumb to the vicious lies of an unscrupulous industry. Unfortunately, most will never know it. Most will never see the immediate undermining of their property value or the long term destruction of the structure of their house. And what is this vicious lie? Vinyl siding. Vinyl siding installed over wood siding. And the most vicious lie is that it will improve the property value of an historic house.

Debunking the lies

Lie number one: Vinyl siding will increase the value of your home.
As an architect involved in numerous historic restorations, I am frequently asked to evaluate an historic house prior to purchase. In virtually every case where vinyl siding has been used to cover original wood, the buyer wants to know the cost of having the vinyl removed and the original siding restored. In every case the same question comes up; "Why would they desecrate an historic house in this manner?"

Increasingly people across America are understanding the value of our historic properties. Like antiques, the closer it is to original the higher is its value. Frequently, the buyer not only sees vinyl siding as decreasing the value of the house, but wants the seller to pay for its removal. This removal and repair of the original wood siding is normally as expensive as the original installation of the vinyl siding.

Lie number two: Vinyl siding will make your house maintenance free.
There is no such product! Every material, every installation requires maintenance!
Vinyl siding installations require significant caulking, around windows, at corners, around doors, anywhere a "J" channel is used to terminate a run of siding. I have never seen a vinyl siding installation where caulking is installed in accordance with the manufacturer's instructions. Even the very best caulking, when improperly installed, will fail within a few years. And when it does, water will enter. Time to do some maintenance.

Vinyl siding is secured to the house by a nail or staple driven through a tab. This tab is designed not only to hold the siding to the house, but to allow it to move as it expands and contracts with temperature. If the fastener is too tight, the siding may buckle in the heat or break in the cold. This will usually result in the siding coming off the house in a windstorm. This rarely happens immediately. Usually it occurs a year or two after the installation, and after the warranty has expired. In addition, since the higher areas of the house are subjected to more wind, that is where the damage is most likely to occur. More maintenance, and maintenance the average homeowner cannot do.

Vinyl siding commercials will show you how the siding can withstand a blow from an object like a hammer. What they do not tell you is that the longer siding is on the house the more brittle it will become. Ten years later, that same piece of siding, exposed to the elements, may crack or even shatter under the same blow. A blow from a tree limb or from a ball and you have more maintenance.
In short, vinyl siding is not maintenance free.

Lie number three: You will never have to paint again.
Maybe we shouldn't call this a lie. The truth is, you never can paint again. Even the best vinyl siding will fade. The deeper the color, the faster it will happen and the more noticeable it will be. In 10 to 15 years vinyl siding will show a significant change in color.

Vinyl siding will also become dingy through an accumulation of dirt. Contrary to what the commercials would have you believe, we are talking about dirt that spraying with a garden hose will not remove. In ten to fifteen years many home owners are dissatisfied with the dingy look of their siding and want to do something to restore it. (Sounds like maintenance, doesn't it?)

Sorry folks, not a lot you can do. Scrubbing the siding with soap and water (not just spraying it) will help a little. While that is faster than painting, it is far less satisfactory. Painting, however, is totally out of the question. At this time there are no paint manufacturer's I am aware of that will guarantee their paint over vinyl siding. Within a few years the paint will begin to peal.

By the way, if you do decide to wash your vinyl siding, never use a high pressure sprayer. The high water pressure may force water around the siding and through bad caulk joints into your house. Further, the high pressure may loosen the siding, or even remove whole sections that are already loose.

Lie number four: Vinyl siding will save you money.

In spite of what the manufacturers would have you believe, the life expectancy of a high-quality vinyl siding installation is approximately 20 to 30 years. The life expectancy of a high-quality, professional paint job is approximately 10 to 15 years. Since the vinyl siding installation will cost approximately twice that of painting, there is virtually no savings.

Should you choose to remove the old vinyl siding at the end of its life, you now incur the cost of removal as well as the cost of the new installation. At this point painting has become far less expensive.
Now that we've discussed what they do tell you, let's talk about what they don't tell you, and hope you will never discover.

Destruction of details

When you look at an historic frame house, you will notice a significant amount of detail. This may include moldings and brackets at the eaves, details in the siding such as fish scales or beaded edges, headers over windows and doors, and shadow lines at window and door trim. Virtually all of this is covered up when vinyl siding and vinyl eaves are added to a house. In addition, eave details such as brackets and moldings are frequently removed to facilitate the installation of the vinyl material. In short the installation of vinyl siding and eaves significantly reduces the character of the house.

To the individuals seeking to purchase an historic home, the installation of vinyl siding and eaves has not improved the value of the house but rather has destroyed the character for which he/she is looking. Therefore, the value of the house has been significantly reduced.

Destruction of Walls.

In a typical historic house of wood frame construction a wall would normally be composed of the following: plaster on wood lath, the wood studs, exterior sheathing, and wood siding. While these materials may seem solid to us, water vapor easily moves through these materials and escapes from the house during the winter months.

During the installation of vinyl siding a layer of styrene insulation board is applied over the wood siding, and the vinyl siding is applied to that. This insulation board forms an effective barrier to the passage of water vapor, thereby trapping it within the wall. During the winter months this water vapor will condense to liquid water and began rotting the wood materials. Over a period of years the structural integrity of the exterior walls can be completely destroyed. Further, the presence of deteriorating wood has been shown to attract termites and other wood attacking insects.

In summary, it is my opinion based on my experience as an architect that vinyl siding is not maintenance free, and it is not less expensive than painting. It is also my opinion that vinyl siding destroys the aesthetic quality of an historic house, and decreases its value, and can, over time, destroy the structural integrity of the house.

Like many products, vinyl siding has a place. It works adequately in inexpensive new construction where proper precautions are taken to prevent water damage. However, when the industry tries to sell this product as a maintenance free improvement to older homes, they are doing the public a great disservice. And when it comes to historic homes, they are costing you money.

Gary Kleier is the resident Old Louisville Architectural Conservator. He lives on Floral Terrace and is one of those folks who was instrumental in the landscaping and beautification of that little jewel of a walking court between Sixth and Seventh Streets. Gary specializes in restoration architecture and architectural forensic services and has a wide range of talents which are described on his own web site at http://www.kleierassociates.com/. This is reprinted with his permission.

Let the Numbers Convince You: Do the Math

U-Value = A measure of air-to-air heat transmission (loss or gain) due to thermal conductance and the difference in indoor and outdoor temperatures

TUNE-UP STRATEGIES	Storm window over single-pane original window	Double-pane thermal replacement of single-pane window	Low-e glass double-pane thermal replacement of single-pane window	Low-e glass double-pane thermal replacement of single-pane window with storm window
ANNUAL ENERGY SAVINGS	722,218 Btu	625,922 Btu	902,772 Btu	132,407 Btu
ANNUAL SAVINGS PER WINDOW**	$13.20	$11.07	$16.10	$2.29
SIMPLE PAYBACK	$50/$13.20 = 4.5 Years	$450/$11.07 = 40.5 Years	$550/$16.10 = 34 Years	$550/$2.29 = 240 Years

*Cost of 3' x 5' window, installed

**Assuming gas heat at $1.09/therm

U-Value = A measure of air-to-air heat transmission (loss or gain) due to thermal conductance and the difference in indoor and outdoor temperatures

Source: Keith Haberern P.E., R.A. Collingswood Historic District Commission

JOHN VAN PELT

PRESERVATION RESOURCES, INC
Bob Yapp-574-283-0630
Updated 9-17-08

A COST BREAKDOWN FOR WINDOW RESTORATION V.S. WINDOW REPLACEMENT

The following is a break down of the costs to **completely** restore & weather- strip two original wood sashes in a double-hung window opening, including a new wooden storm window. It is important to note that often, total paint removal, epoxy repair, new glass, new interior stop-molding, etc. isn't needed.

Window sash and jambs that are **completely** restored have a life of another 100 years with painting every 12 to 20 years depending on conditions. With the wooden storm they also exceed the u-value and r-value of a comparable replacement as described in the next paragraphs.

Replacement with two new wooden sashes in an original 33" X 67" double hung jamb unit with four, true divided lights on the top and one light on the bottom will run $800 to $1,200 for single pane with no storm window. Double paned glass in the new wood sash would raise the cost to $1,000 to $1,400 per unit installed with no storm.

Commercial grade, double paned aluminum sashes with fake divided light muntins and spring balances in the same size opening will run $1,200 to $2,000 with no storm.

The restoration labor time estimates below are based on a worker that is experienced in this type of window restoration process. They also are accumulated time, not consecutive time. In other words, if you apply primer and two topcoats there is dry time in between when other work is performed.

(A) is a traditional wood storm with putty glazed, fixed glass. (B) is a traditionally constructed wood storm with removable glass and screen from inside the house or building.

(A)

MATERIAL & LABOR TO RESTORE A <u>DOUBLE HUNG WINDOW UNIT</u> 33" X 67" OPENING WITH A 4 LIGHT TOP SASH & ONE LIGHT BOTTOM SASH, INCLUDING NEW, <u>TRADITIONAL WOOD STORM</u>

Materials

What	Description	Cost
Storm Window	Factory primed traditional wood storm 33" x 67"	$150.00
Glazing Putty	Linseed oil based glazing compound	$.65
Weather Stripping	Rigid metal with EPDM rubber tube for storm	$12.40
Weather Stripping	Dorbin Strip Metal double hung weatherizing system with shipping	$14.15
Glass	Double strength glass, 4 lights per upper sash & 1 light on lower @ $4.00 per square foot	$32.00
Storm Hardware	Traditional storm hangers and 2 hook & eyes	$4.50
Sandpaper	100 grit 5" sanding disc- 2 pieces	$.30
Epoxy	Architectural epoxy wood filler-liquid & putty	$4.50
Tack Cloths	For cleaning bare wood surface	$.29
Glazing Points	For setting glass	$.20
Caulk	Acrylic Latex caulk with silicone for bedding glass	$1.00
Sash Cord	Nylon braided sash cord	$1.50
Moldings	New interior finish stop & parting stop	$8.50
Primer	Alkyd oil based primer with linseed oil-sash only	$2.25
Paint	Acrylic latex semi-gloss, 2 top coats-sash & storm	$3.50
Total Material Costs with Traditional Wood Storm		**$235.74**

Labor @ $25 Per Hour

Task	What	Time	Cost
Sash removal	Remove sash from jamb, take off all hardware	.50 hrs	$12.50
Paint & Glazing Removal	Infrared paint removal from jamb. Infra red paint removal from glazing from sash	2.00 hrs	$50.00
Repair Sash	Re-pin or repair with wood or epoxy	.50 hrs	$12.50
Clean & Prime all	Tack-off, clean & oil prime	.75 hrs	$18.75
Glaze	Set glass in caulk with points & glaze	.50 hrs	$12.50
Paint Sash, Storm & Jamb	Apply and cleanup Two top coats	1.00 hrs	$25.00
Hardware	Buff or wire wheel & lacquer or spray paint.	.25 hrs	$6.25
Weather-Stripping	Cut sash slots & install weather-stripping-sash & storm	1.00 hrs	$25.00
Hang Storm & Sash	Re-hang two sashes & one storm with hardware	1.50 hrs	$37.50
Total Labor Costs with Traditional Storm		**8.00 hrs**	**$200.00**
Total Material Costs with Traditional Storm			**+$235.74**
Total Window Restoration Costs with Traditional Storm			**$435.74**

NOTE: This is absolute worst-case/total restoration scenario, with all work being hired done.

(B)

MATERIAL & LABOR TO RESTORE A DOUBLE HUNG WINDOW UNIT 33” X 67”OPENING WITH 4 LIGHTS ON TOP SASH & ONE LIGHT ON BOTTOM SASH INCLUDING NEW, COMBINATION WOOD STORM/SCREEN

Materials

What	Description	Cost
Storm Window	Factory primed traditional wood storm 33” x 67”	$200.00
Glazing Putty	Linseed oil based glazing compound	$.65
Weather Stripping	Rigid metal with EPDM rubber tube for storm	$12.40
Weather Stripping	Dorbin Strip Metal double hung weatherizing system with shipping	$14.15
Glass	Double strength glass, 4 lights per upper sash & 1 light on lower @ $4.00 per square foot	$32.00
Storm Hardware	Traditional storm hangers and 2 hook & eyes	$4.50
Sandpaper	100 grit 5” sanding disc- 2 pieces	$.30
Epoxy	Architectural epoxy wood filler-liquid & putty	$4.50
Tack Cloths	For cleaning bare wood surface	$.29
Glazing Points	For setting glass	$.20
Caulk	Acrylic Latex caulk with silicone for bedding glass	$1.00
Sash Cord	Nylon braided sash cord	$1.50
Moldings	New interior finish stop & parting stop	$8.50
Primer	Alkyd oil based primer with linseed oil-sash only	$2.25
Paint	Acrylic latex semi-gloss, 2 top coats-sash & storm	$3.50
Total Material Costs with Storm/Screen Wood Combination		**$285.74**

Labor @ $25 Per Hour

Task	What	Time	Cost
Sash removal	Remove sash from jamb, take off all hardware	.50 hrs	$12.50
Paint & Glazing Removal	Infrared paint removal from jamb. Infra red paint removal from glazing from sash	2.00 hrs	$50.00
Repair Sash	Re-pin or repair with wood or epoxy	.50 hrs	$12.50
Clean & Prime all	Tack-off or clean with TSP & oil prime	.75 hrs	$18.75
Glaze	Set glass in caulk with points & glaze	.50 hrs	$12.50
Paint Sash, Storm & Jamb	Apply and cleanup Two top coats	1.00 hrs	$25.00
Hardware	Buff or wire wheel & lacquer or spray paint.	.25 hrs	$6.25
Weather-Stripping	Cut sash slots & install weather-stripping-sash & storm	1.00 hrs	$25.00
Hang Storm & Sash	Re-hang two sashes & one storm with hardware	1.50 hrs	$37.50
Total Labor Costs with Storm/Screen Wood Combination		**8.00 hrs**	**$200.00**
Total Material Costs with Storm/Screen Wood Combination			**+$285.74**
Total Window Restoration Costs with Storm/Screen Wood Combination			**$485.74**

NOTE: This is absolute worst-case/total restoration scenario, with all work being hired done.

Rubber Gasket Material for Meeting Rails and Bottom Rail of Lower Sash

Dorbin Metal Strip Mfg. 773-242-2333. Item #199S-"Santoprene". 67 cents per foot. Use a 3/32" slotting bit and clear silicon caulk to secure it in the slot.

BASIC TOOLS & SUPPLIES
FOR DOUBLE-HUNG, WOOD WINDOW RESTORATION

PRESERVATION RESOURCES, INC
Bob Yapp-573-629-2226 or yapperman@msn.com

TOOLS

Window Removal
* Window zipper.
* Utility knife.
* Utility knife blades
* Numbered die stamps (to mark for replacement in correct jamb).
* Screw drivers.
* Small, flat ply bar.

Restoration
* Speed Heater – infrared heating devise to remove lead paint safely.
* Spray bottle - to mist wood before scraping.
* Carbide scraper - for 2” blades.
* Profile scrapers & pull-shave scrapers.
* 1.5” stiff putty knife for applying glazing putty
* Bastard file to sharpen profile, steel scraper blades
* Orbital Palm Sander, 5” with dust bags or a sanding block.
* Wood chisels.
* Sharpening stone & oil.
* Large garbage can (to break glass out of sashes on top of).
* Hammer & nail set.
* C-clamps, Quik-Grip Clamps- lots.
* 3/4” Bar Clamps- lots.
* 2 1/2”, quality, angled bristle, trim paint brushes. One set for oil & one for latex.
* Exhaust fan for fumes.
* Double filtered face mask with lead cartridges.
* Compressor with blower.
* Bench grinder with wire wheel and/or cotton buffing wheel to clean-up hardware.
* Caulk guns.
* Table saw with thin kerf blade or router with slot bit for slotting edges for Dorbin system.
* Off-set, dovetail saw.
* HEPA vacuum or shop vacuum with drywall filters.

SUPPLIES
* Carbide scraper blades. 2” - lots of them.
* Profile steel scraper blades. Several different profiles (curved etc.)
* 100 & 120 grit, orbital sticky disks with dust holes.
* Abatron Liquid Wood & Wood Epox - two parts each.
* Glazing compound & glazing points. (no DAP! Use compound with linseed oil)
* #10 galvanized casing/finish nails (used as new mortise & tenon pins)
* Wood screws & cup washers for re-installing parting and finished stop.
* Tack cloths.
* Acrylic latex, siliconized caulking.
* Primer - alkyd oil based.
* Paint thinner.
* Brush cleaner - the type that spins around.
* Acrylic latex paint or oil enamel - color to be determined.
* Aerosol spray paint - matte black for pulleys.
* Dorbin Metal Window Weather-Stripping System.
* Storm window weather-stripping - from Dorbin or hardware store.
* Boxes of cotton rags.

PRESERVATION RESOURCES

OLD HOUSE STUFF BOB YAPP USES

SASH-METAL WEATHER STRIPPING
Dorbin Metal Strip Manufacturer, Inc.
2404-10 S. Cicero Ave.
Cicero, IL. 60804-3492
1-773-242-2333

PULLEY COVERS
Blaine Window Hardware Co.
l7319 Blaine Drive
Hagerstown, MD 21740, Ph- 800-678-1919

SCREEN-STORM WINDOW COMBO
Adams Architectural Eldridge, IA
319-285-8000
1-888-285-8120

Acker Millwork Co.
3300 W. Pabst
Milwaukee, WI 53215

BEVEL CEDAR SIDING (Pre-painted)
Cabot Stains (only make the stain)
800-877-8246
Also: Olympic Stains

Westside Forest Products
RR # 3, Box 303
Bloomington, IL. 61704, Ph.- 309-827-4717
(factory painted 6 sides, cedar clapboard smooth & factory stained fiber cement siding)

CLAY TILE ROOF MFG.
Ludowici Roof Tile, Inc.
Box 69
New Lexington, OH 43764

MORTAR TESTING
The Collaborative, Inc.
1002 Walnut, Suite 201
Boulder, CO 80302, Ph- 303-442-3601

David Arbogast
Architectural Conservator
Mortar, Stucco, Paint & Plaster Analysis
Iowa City, Iowa 52247 Ph- 319-351-4601

MORTAR TESTING (Continued)
US Heritage Group
1-773-286-2100
Contact: John Speweik
(mortar analysis - will match mortar for color & original mix & supply it to you pre-mixed and ready to go - supplier of lime putty mortar)

PAINT SHAVER MFG
American International Tool
1140 Reservoir Ave., Suite L01
Cranston, RI 02920, Ph- 800-932-5872

HALF-ROUND GUTTERS
Historic Gutter Systems
5621 East "DE" Ave.
Kalamazoo, MI 49004, Ph- 616-382-2700

PULLMAN MFG. CORP.
(Counterbalances for windows)
77 Commerce Drive
Rochester, NY 14623
Office 716-334-1350, Fax 716-359-4460

STEEL WINDOW REPAIR
Seekircher Steel Window Repair
Scarsdale, NY
John Seekircher, 914-725-1904

NU WALL & RECYCLED RUBBER
Specification Chemicals
Boone, IA, Ph- 800-247-3932
Also: Glid-Wall by Glidden Paints

PLASTER WASHERS
Charles Street Supply Co.
54-56 Charles Street, Dept. OH
Boston, MA 02114, Ph- 800-382-4360

ARCHITECTURAL EPOXIES
Abatron, Inc.
LiquidWood & WoodEpox
Kenosha, Wisconsin
1-262-653-2000

THE SPEED HEATER
Safe, infrared paint removal tool
703-476-622

NOTICE
The attached list of names should be used as a guide for selecting products and services. While many of the companies and products named in this list have been successfully used on/with historic properties, their listing in no way constitutes a recommendation or endorsement by Bob Yapp. You are encouraged to check references as well as review the work, products and services prior to making any selection for your projects.

An Analysis of the Thermal Performance of Repaired and Replacement Windows

ROBERT SCORE AND BRADFORD S. CARPENTER

Data and analysis of in-situ thermal monitoring reveal that the repair of aging steel windows offers the opportunity to retain historic building fabric and secure a level of energy performance that can match or exceed that of modern aluminum-framed replacement windows.

Fig. 1. Southwest elevation, Lafayette Building, Vermont Avenue and H Street NW, Washington, D.C. The building's neoclassical exterior has regularly placed, double-hung steel windows. All images by authors.

Introduction

As federal buildings that were constructed to support the expanding role of the U.S. government and the war effort during the late 1930s and 1940s reach the end of their useful lives, their caretakers are embarking on rehabilitation and modernization projects to meet modern and often greatly expanded performance standards. The original window systems often lack the construction detailing and other characteristics needed to provide a level of performance acceptable for modern office space, such as humidification and energy performance. Many of these window systems have suffered years of neglect and deferred maintenance and owe their longevity largely to the durability of original materials, the robustness of the original construction, and layers upon layers of paint.

A common and as-yet unresolved issue is the final fate of these windows. More often than not, building-renovation projects call for the replacement of original windows with modern replicas rather than the rehabilitation of the existing windows, often under the guise of improving energy performance or occupant safety (blast resistance), with little thought given to the embodied energy in the existing windows or the whole-life energy commitment of the new product. This consideration becomes even more crucial when considering the demands of achieving LEED ratings in a renovation project.

One structure currently being considered for such renovation is the Lafayette Building, a federal office building located in downtown Washington, D.C. (Fig. 1). Originally housing the Export-Import Bank of the United States and more recently the Department of Veteran Affairs, the Lafayette Building has had a long and storied history of federal use and is being proposed for a significant modernization project. Built in 1940 and designed by the Chicago architectural firm of Holabird and Root, it is a National Historic Landmark.

The building has nearly 1,200 windows along the primary facades and a single interior light court. The windows are constructed of steel shapes and were installed in a double-hung configuration (Fig. 2). The windows are approximately 54 inches wide and 72 inches high and have single glazing without intermediate muntins. Many of the windows exhibit paint flaking and some surface rusting, while others have more significant rusting, particularly at the base of the jambs (Fig. 3). The windows are currently operable and have counterweights in concealed weight pockets. This paper discusses a brief study comparing two options for treating the windows during the planned repair program.

Performance Requirements and Design Options

The Lafayette Building is scheduled to undergo a comprehensive renovation, including upgrades to the mechanical and electrical systems, reprogramming and renovation of interior spaces, and renovations to all exterior facades, including upgrading the windows for blast resistance in accordance with requirements of the General Services Administration (GSA), the building owner. In order to assist the building owner in selecting the most appropriate treatments for the windows, an overall design program for the windows was developed. It identified the performance requirements for the windows, including the following:

- provide blast resistance per GSA requirements.

Fig. 2. View of an unrepaired steel-framed window on the east elevation of the Lafayette Building. Note the loss of paint coatings and corrosion of the built-up steel frame.

- preserve the original window sash and frames where possible, including original materials, configuration, dimensions, sight lines, and profiles, as well as the clarity and reflectivity of the original glazing. Any replacement windows must match existing window configuration, dimensions, sight-lines and profiles, as well as the clarity and reflectivity of the original glazing.
- improve energy performance and reduce air infiltration and water penetration at the windows.
- provide windows that are easily maintainable.
- provide a cost-efficient treatment.

These performance requirements were used to develop design options, evaluate the technical options, and then help select the most appropriate treatment. Based on the existing conditions and the design requirements, the following two options were identified:

Option 1. Repair the existing steel windows and provide a supplemental interior storm window that meets the blast requirements and also improves the thermal performance of the existing window. The window frame would not be removed from the window opening during repair. The sash would be removed, repaired, and reinstalled; all steel would be prepared to SSPC-SP3, the standard specification for power-tool cleaning of steel surfaces by the Society for Protective Coatings (SSPC), and given two coats of acrylic enamel paint. The exterior light of glass, a single pane of clear float glass, would be retained where possible. Blast resistance requires that the original sash be fixed shut. A blast-resistant aluminum-framed storm window would be installed on the interior face of the window, approximately 3 inches from the face of the glass in the lower operable sash. The storm window would include a single laminate sheet of glazing that includes low-E glass with a high solar heat-gain coefficient (SHGC) to provide improved passive solar heat gain.

Option 2. Replace the existing windows with new blast-resistant, thermally broken, aluminum-framed windows with 1-inch insulating glazing. The new windows would closely match the existing configuration, dimensions, profiles, and sight lines of the original windows. Original windows would be removed from the opening; interior finishes would be removed from the perimeter of the window; and modifications made to the perimeter substrate and trim to allow installation of mounting clips to secure the replacement windows to the masonry back-up. Interior finishes would then be repaired to conceal the anchorages. The replacement-window insulated-glass unit would include low-E glass that has a high SHGC glazing, which would minimize passive solar heat gain. The operable sash would be fixed shut to meet blast requirements. More historically accurate steel replacement windows were not considered for this option as they were cost prohibitive compared to restoring the existing windows as described in Option 1 and offered little thermal-performance improvement over the existing windows.

Window Mock-ups

To assist in evaluating the two options, in-situ mock-ups of both options were installed in the building, allowing for a review of aesthetic impacts, constructability, and cost, as well as testing and monitoring of the thermal performance.[1] These mock-ups were constructed using the same materials and treatments proposed for the actual construction in order to provide accurate results for comparison (Figs. 4 through 7). Mock-ups were installed in the east elevation of the building at the eleventh-floor level based upon input from the owner and design team. The location on the east elevation of the eleventh floor, a height roughly equal with the rooftops of surrounding building, allowed a relatively unobstructed solar exposure and conditions that vary between the diffuse solar radiation of north exposures and the intense solar radiation of south and west exposures.

Performance Monitoring

The monitoring study was undertaken in 2006 by Harboe Architects and Simpson Gumpertz & Heger, Inc. (SGH). The purpose of the study was to document and evaluate the performance of a repaired window and a proposed replacement window under similar exposures and to provide direction and feedback to the design team for incorporation into the rehabilitation program. The monitoring system allowed for the recording of surface and air temperatures, as well as relative humidity for multiple locations.

The two mock-up windows were monitored between March and July 2006. Though the duration was limited to just over three months by program and tenant constraints, sufficient data was gathered to compare the performance of the mock-ups over a significant range of exterior conditions. This recorded performance allowed for the extrapolation of performance outside of the range of measured interior and

Fig. 3. View of a steel window sill on the east elevation of the eleventh floor. Note the significant corrosion of the steel frame at the sill-to-jamb corner.

Fig. 4. Sill of the replacement window.

Fig. 5. Sill of the repaired window.

exterior conditions. Though relatively limited in scope and duration, this study provided valuable real-world performance information, which was used to help guide the design team in the evaluation of potential treatment options. Additional analysis using computer simulation and other analytical tools could be used to further develop performance characteristics, such as evaluating other exposures and other glazing options.

Setup and procedure. Surface temperatures, ambient conditions, and the heat gain and loss experienced through each window were measured in order to fully evaluate and compare the thermal performance of the two mock-ups. A sealed chamber was installed on the interior face of each specimen window. The chambers were insulated, and the interior surface of each chamber (facing the window) was covered with a reflective white coating to minimize unwanted solar heat gain within the chamber. An air inlet was installed at the top of the chamber, and an outlet with an electric fan was installed at the bottom to ventilate the chamber with a known quantity of air. The air inlet and outlet temperatures were measured using thermistors and recorded on a data logger. The change in temperature between the inlet and outlet was used to calculate the heat gain or loss through the window, as described below.

Both window mock-ups were instrumented with surface-temperature sensors (thermocouples) at critical frame and glass locations where maximum and minimum surface temperatures are expected to occur, such as at the center of the glass, the horizontal meeting rail, and perimeter frame locations. Relative-humidity and air-temperature sensors were also installed within the air cavity between the storm glazing and the exterior window to evaluate condensation potential within the storm cavity (Figs. 8 and 9). Ambient conditions were recorded on the building's exterior and interior, including the pressure differential between the interior and exterior conditions, using relative-humidity and temperature sensors and a digital pressure gauge. Data points for accessible locations were recorded on a laptop computer, while inaccessible data points (temperature and relative humidity within the storm of the rehabilitation window) were recorded on stand-alone data loggers.

Heat-flow calculations. Following data collection, raw temperature and humidity data were used to calculate the heat loss or gain through each window. Window heat-flow calculations were made by comparing the temperature of the air entering the insulated chamber to the temperature of the air leaving. The humidity ratio was calculated using interior temperature and relative humidity, allowing calculation of the change in enthalpy of the air as it entered and exited the chambers.[2] Formulas for air properties are found in the *ASHRAE Handbook: Fundamentals* 2005.

This analysis method produces representative heat flows for comparison; however, the method has some error because it does not account for the dynamics of constantly changing boundary conditions. Also, the data comparisons produced anomalies when one window heat flow indicates a thermal loss or gain while the other window indicates the opposite. The heat-flow analysis compares only the loss at one window to the simultaneous loss at the other window and the gain at one window to the simultaneous gain at the other window, while ignoring the time periods when the windows indicated opposing flows, which is limited to less than 10 percent of the data where flux approaches equilibrium between gains and losses. Overall, the effect of these two minor simplifications on the overall comparative thermal analysis was considered negligible.

Results

The analytical review of the thermal performance of the two mock-up windows was a complex process with many obvious variables, as well as several that were not so obvious. The main variables considered were heat gains and losses due to conduction through the window frame and solar heat gain (radiation) through the glass, as these were the most significant mechanisms for heat transfer through the window assembly. The mock-up apparatus was designed to determine heat gain and loss, as noted above. However, it was not capable of isolating conductive heat loss or gain from solar heat gain without additional processing of the data. In order to isolate conductive losses from solar gain, the data indicating heat loss was isolated from the data indicating solar gain (i.e., daytime conditions with solar exposure) where possible. As most conductive heat-gain opportunities during the monitoring were during the warmer, sunny hours of the day, conductive heat gain was unable to be isolated from solar heat gain. Therefore,

Fig. 6. Head of the replacement window.

Fig. 7. Head of the repaired window. Note the similar sight lines but missing articulations and accessories of the replacement window when viewed in conjunction with the repaired window.

conductive performance is best measured during nighttime conditions during colder temperatures (i.e., night conditions with no solar exposure and large thermal gradient across the mock-up). Total heat gain and loss through the windows were then calculated (Table 1).

Solar heat gain. As expected for the east-facing windows, solar heat gain is the largest source of heat gain for the window system and spikes for both window mock-ups in the late morning when the windows are most exposed to sunlight. Heat gain tapers off in the afternoon as direct solar exposure decreases due to indirect diffuse solar exposure. There was a significant difference in peak heat gains between the two mock-up windows (Fig. 10).

Calculations show that the daily peak solar heat gain for the repaired window was approximately 35 to 40 percent greater than for the replacement window during the coldest week of monitoring. In addition, the net heat gain also included reductions in heat gain due to conductive heat loss through the window unit, which was greater for the replacement window, as noted below. As expected, when comparing the measured performance during warmer weather, the difference between the peak heat gains of the two windows was smaller (Fig. 11).

Calculations reveal that the peak solar heat gain for the repaired window was only 10 to 25 percent greater than that of the replacement window during the warmest week. A comparison with the solar gains during the coldest week illustrates the improved conductive heat gain and loss performance of the repaired window mock-up with respect to the replacement window mock-up. Heat loss was calculated to be 4.0 kW for the replacement window and 1.5 kW for the repaired window during the warmest week. When daytime solar heating conditions (net heat gain for both windows) were considered, a heat gain of 150.6 kW for the replacement window and 169.3 kW for the repaired window was calculated during the coldest week. The net heat gain/loss for the week (excluding conditions where one window is experiencing heat gain or loss and the other window is experiencing the opposite) for each window was found to be 146.6 kW gain for the replacement window and 167.7 kW gain for the repaired window. The repaired window experienced approximately 15 percent more heat gain during the warm week.

Conductive and radiation heat loss and gain. Conductive heat loss or gain occurs through the frame of the window and was the primary mode of energy loss through the window-frame assembly. Radiation heat loss or gain occurs through the glazing assembly and was the primary mode of energy loss through the window. Conductive and radiation heat losses and gains are driven by temperature differential across the window and are easiest to measure during cold winter months, when the temperature differential across the window is greatest. However, conductive and radiation heat gains can occur during summer months when exterior temperatures are greater than the conditioned interior temperature. Since hot-weather conductive and radiation heat gains occur during the hottest part of the day when solar gain is peaking, it was not possible to separate solar and conductive gains through the window, and the data therefore were not separated in the analysis.

The coldest exterior temperatures were observed during the first week of monitoring. Temperatures were not as cold as typical peak winter conditions.[3] However, they provided adequate opportunity to measure window performance during cold weather. Heat-loss data was isolated from the heat-gain data, and the differences in the daily peak heat loss for each of the windows were compared for this cold week (Fig. 12).

As expected, heat-loss peaks occurred in the very early morning hours, before solar heat gain begins. The repaired window experienced 15 to 35 percent less heat loss through the window than the replacement window during the coldest week. Heat loss was calculated to be 121 kW for the replacement window and was 89.5 kW for the repaired window during the week. Considering daytime solar heating conditions (net heat gain for both windows) only, a heat

Table 1. Heat Gain and Loss Totals for the Two Mock-up Windows over a Testing Period of Approximately 12 Weeks

Specimen	Net Heat Loss (kW)	Net Heat Gain (kW)
Replacement Window	-419.1	994.6
Repaired Window	-296.9	1264.8

gain of 33.1 kW for the replacement window and 62.1 kW for the repaired window was calculated for the coldest week, a significantly smaller heat flux than with conductive losses alone. The net heat gain or loss for the week for each window (excluding conditions where the mock-ups are experiencing opposing heat flows) was found to be 87.9 kW loss for the replacement window and 27.4 kW loss for the repaired window. The repaired window experienced nearly 70 percent less heat loss during the cold week. It is important to understand that as the exterior temperature drops, the heat loss (and difference in heat loss) for the windows will increase and that this difference in performance would be expected to become more pronounced during typical peak wintertime conditions. Thus, the conductive gains during hot weather are inversely proportional to the losses.

Fig. 8. Interior view of the repaired window prior to installation of the interior chamber. Note the thermal and relative-humidity sensors are indicated with dots. Some sensors are installed on the repaired window, and others are installed on the storm sash, resulting in more sensor locations than on the replacement window.

Fig. 9. View of the replacement-window mock-up prior to the installation of the interior chamber. The temperature sensors are indicated with dots.

Discussion

The purpose of this study was to compare differences in thermal performance of the two window mock-up specimens under identical operating conditions. After analyzing the monitoring data, several trends became apparent, and they may impact the selection of the window-treatment option for the repair and replacement program. To better understand the results of the testing and monitoring, it is essential to have a general understanding of window performance. The pertinent performance factors and observations are discussed below.

Solar heat-gain performance. The most significant component of heat gain is solar heat gain through the window glazing. Several factors affect the solar heat-gain performance of windows, including the geometry and configuration of the window unit (such as the amount of clear window opening), its placement and orientation, the type of glazing and coatings used, and the amount of interior and exterior shading. Optimizing these characteristics to improve thermal performance can significantly improve building operating costs and occupant comfort.

Window configuration. The configuration and geometry of a window affects its solar heat-gain performance. For example, a window with a wide frame and numerous small lights separated by mullions and muntins has less glazing area available to capture solar energy. By contrast, a window in the same rough opening with a thin frame and one large light will have a greater proportion of glass-to-frame area and will allow more sunlight into the building interior. Both mock-up windows had similar construction, with large unobstructed glazing areas and narrow metal perimeter frames. Therefore, the difference in performance due to frame configuration and design was small.

Window orientation. Placement and orientation of the window with respect to compass direction is the root factor affecting solar gains. West- and south-facing windows experience the most significant gains, but some gain is possible in all directions from diffuse sky radiation. The majority of the windows at the Lafayette Building are on the east, west, and north elevations, with very few windows facing due south. Both mock-up windows faced east, and therefore the recorded data represents only one of the four possible orientations existing on the building, a limitation of the study scope and budget.

During the winter the low elevation of the sun at midday causes it to shine through south-facing windows, in addition to east-facing windows in the morning and west-facing windows in the afternoon. The resulting solar gains can help reduce heating costs during the winter. In the summer, when the sun is much higher at midday, the angle of incidence of the solar radiation is much sharper. Consequently, more solar radiation reflects off of south-facing windows than is transmitted to the interior. Overheating in summer therefore tends to occur more frequently at unshaded west-facing windows and, to a lesser extent, at east windows than at windows that face directly south. The desired amount of summer and winter solar heat gain is determined by the design of the mechanical system for the building. If the primary load on the building is heating during winter, then optimizing solar heat gain during winter months should dictate window-performance requirements.

Glazing coatings. The number and type of glazing layers and coatings will also affect the thermal performance of the

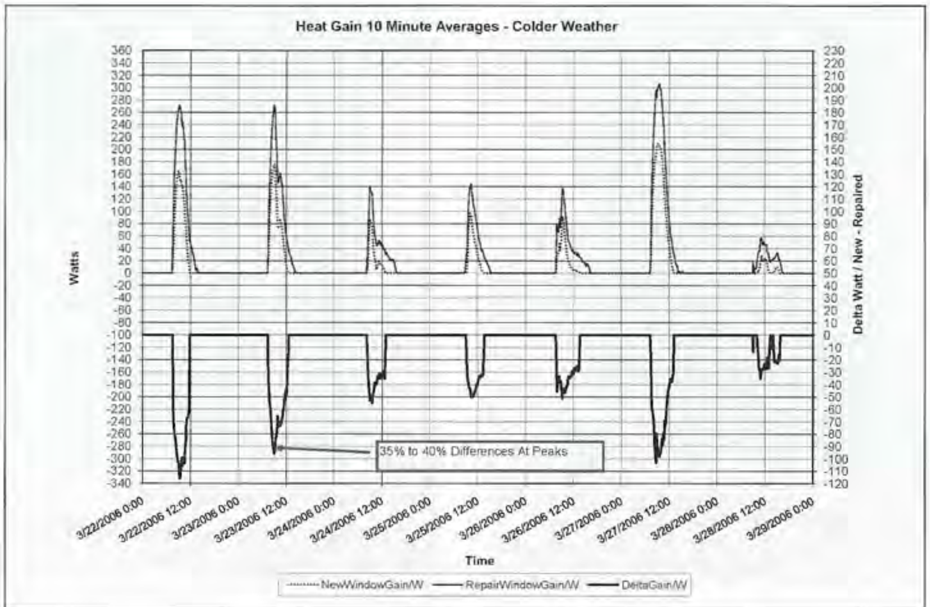

Fig. 10. Heat gain during the coldest week.

windows. For example, a double-glazed, insulated glass unit consisting of ordinary clear glass reduces solar gain by approximately 10 percent compared to a single-glazed window with the same glazing area. Since both mock-up windows included two layers of glazing, the glazing is not a differentiating factor. The addition of glazing coatings have a more significant impact. Low-emittance (low-E) coatings are microscopically thin metal or metallic-oxide layers or a film coating deposited on the surface of the glass (typically on a surface within the glazing cavity) to reduce the U-factor (the heat transfer through the glazing) by suppressing radiation heat flow.

The difference in solar heat gain between the repaired window and the replacement window is likely due to the location and type of glazing coating on the two window mock-ups, in addition to the configuration of the glass. The replacement window had a low-E coating with a relatively low solar heat-gain coefficient (SHGC) in the outer pane of glass. The low-E coating has a SHGC of 0.41, meaning that 41 percent of the solar heat gain is absorbed and transmitted through the glazing, while the rest is reflected back to the exterior. The repaired window has a low-E coating with a higher SHGC on the repaired window storm. This low-E coating has a SHGC of 0.83, meaning that 83 percent of the solar heat gain is absorbed and transmitted through the glazing. This difference in SHGC of the two glazing systems had a substantial effect on the solar heat gain measured in the two mock-ups. Adjusting the heat gains to offset the heating load during the winter or to minimize the cooling load in the summer can be achieved in either window treatment option, in part by the selection of the glazing coating.

If building-load calculations reveal that summer solar heat gain must be minimized, the solar heat-gain performance of the repaired window can be improved with some modification. The least invasive modification involves reducing the low-E coating on the storm window to reduce the solar heat gain. A second option for reducing solar gain through the repaired window would be to add a low-E coating on the inside surface of the exterior glass. The addition of a low-E coating would require replacement of the original glass with a pane of laminated low-E glass (the thermal stress placed upon the original float glass of the existing windows by adding a coating would likely result in glass fracture). Even though there is a diminished benefit to adding low-E coating to the interior storm window rather than to the exterior glass, this procedure does not require replacement of the exterior glass and avoids a change in appearance.

Changes in the position and type of low-E coating on the repaired window may also affect the condensation resistance of the glazing. Although not specifically discussed in this paper, it is important to note here that the most susceptible location for condensation is the interior face of the exterior glass in the repaired window. Adding a low-E coating with a lower SHGC to the interior storm would likely improve condensation resistance of the exterior glass, as would providing a new outer pane of glass with a low-E coating with a mid- to low SHGC.

Other factors. Covering the window openings with draperies and curtains or other shading devices will also reduce the amount of solar heat gain transmitted to the building interior. Keeping the window coverings open to admit as much solar gain as possible on sunny days during the winter will improve performance. This testing did not include interior window treatments, so their impact on thermal performance was not quantified; however, it seems likely that they would impact both mock-ups similarly.

Heat-loss performance. Several processes influence the rates of non-solar heat gain or loss through window components. These processes follow a basic law of thermodynamics: heat energy tends to move from warmer areas to colder areas. In Washington, D.C., the primary flow of heat is from interior spaces to the building exterior during fall, winter, and early spring. The differential temperature tends to be lower during summer months, when heat flow is from the hot exterior to the cooler, conditioned interior. The principal heat-transfer processes in windows are radiation, conduction, and convection. In addition, excessive air leakage can contribute to the overall heat loss.

During colder temperatures, heat is absorbed by the inside pane of a double-glazed window, moves to the cooler outside pane, and is released to the outdoors. Not only does this heat loss take place through the glazing by radiation; it also occurs across the spacer material of the insulating glass unit, which separates the two glazing layers at their edges (at the replacement window only); through the frame of the window by conduction; through the movement of air in the space between the two glazing layers by convection (more pronounced in the larger air space of the repaired window); and between the moveable or operable frame components by air leakage. Convective losses are typically negligible with respect to other losses and were not addressed in this study.

Radiative losses and gains. Typically, radiation losses through the window glass represent about two thirds of the total heat loss in a standard window. Because ordinary glass readily emits heat to colder surfaces (i.e., has a high emissivity), radiation losses can be reduced by lowering the emissivity of the glass by installing low-E films. Placement of the low-E coating in the pane of glass experiencing the greatest temperature differential will have the greatest effect on radiation loss through the window. Review of data from this study indicates the greatest temperature differential is across the outer pane of glass in the repaired window during cold weather. Therefore, placement of the low-E coating in the exterior glass will have the greatest impact on radiative loss.

Conductive losses and gains. Conduction losses in windows occur primarily through the edges and frames of the units and are often expressed in terms of U-value, the overall measurement of conductive heat transfer through the window. The thermal-conductance characteristics or resistance to heat transfer, i.e. R-value of the aluminum frame of the replacement window and the steel frame of the repaired window, also has an effect. Steel is less conductive than aluminum and has a higher R-value, thereby reducing the overall U-value of the window. Data from this study indicate that the temperature drop across the frame was different for the two windows. The thermal break installed in the aluminum-framed replacement window helps to reduce the heat loss across the frame; however, the interior storm window of the repaired window better isolated the steel window frame of the repaired window from the building interior (e.g., no

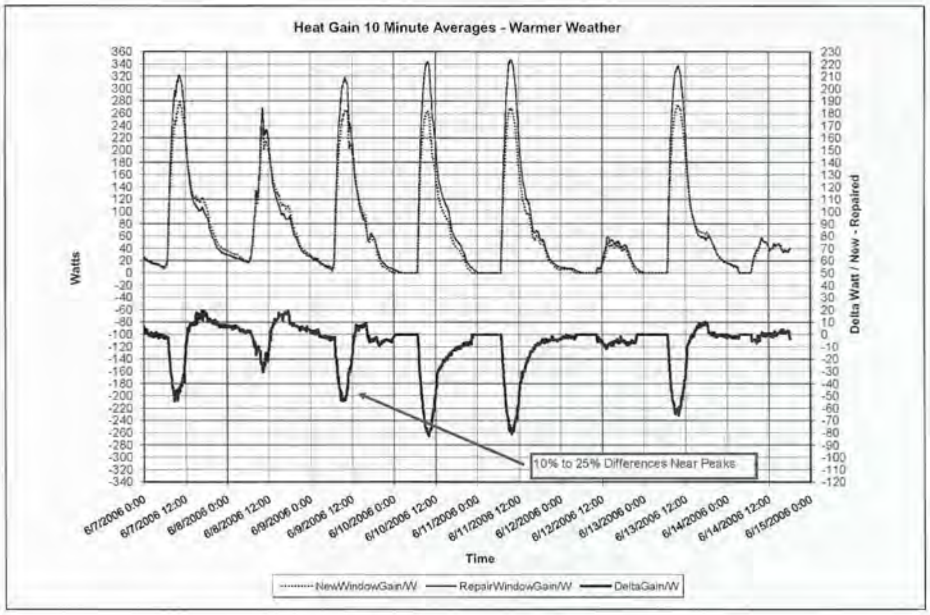

Fig. 11. Heat gain during the warmest week.

metal-to-metal contact at the sash meeting rail), thus reducing heat transfer.

Air leakage. Window air leakage is a significant contributor to energy costs during both heating and cooling seasons for most buildings. Air leakage also affects occupant comfort. Most of the air leakage through operable windows occurs between the window's sash and frame or at the meeting rails of a sliding sash, as on the replacement window. Bigger windows tend to leak less air per unit area than smaller ones. In poorly constructed fixed windows, air leakage also occurs between the insulated glass unit and the frame. Windows with the lowest leakage rates, regardless of type, tend to be fixed windows. Although the repaired window had a fixed sash, it originally was an operable window.

The condition of the perimeter construction also affects the air-infiltration resistance of the replacement window. Air leakage around the replacement window can be a significant problem if the windows are carelessly installed in the rough opening. Air infiltration at and through the perimeter (frame) of the window mock-ups was evident during air-infiltration testing, particularly around the replacement window. Air leakage is likely increased by construction activities to remove the original window and install the new replacement window. Air infiltration around the perimeter of the replacement window can be improved by installing spray foam in the cavity when the original window is removed. Foam will improve thermal performance of the window frame, as well as limit air infiltration. Similar improvements can be made at the repaired window by installing spray-foam insulation in weight pockets and the window perimeter.

Conclusions

This analysis shows significant differences in thermal behavior between the repaired-window and the replacement-window mock-ups. The repaired window experienced more solar heat gain during morning and early afternoon hours than the replacement window. In turn, the replacement window experienced more heat loss through the glass and frame during evening and early morning hours. Because solar heat gain can be manipulated (e.g., through the use of low-E coatings) but heat loss through the frame cannot, the repaired window provides superior heat-loss performance and significantly greater potential for optimizing glazing and heat-gain performance (particularly for the different building exposures) than the replacement window. Solar heat gains for both windows tended to more than offset the heat loss through the frame and glazing, a conclusion that

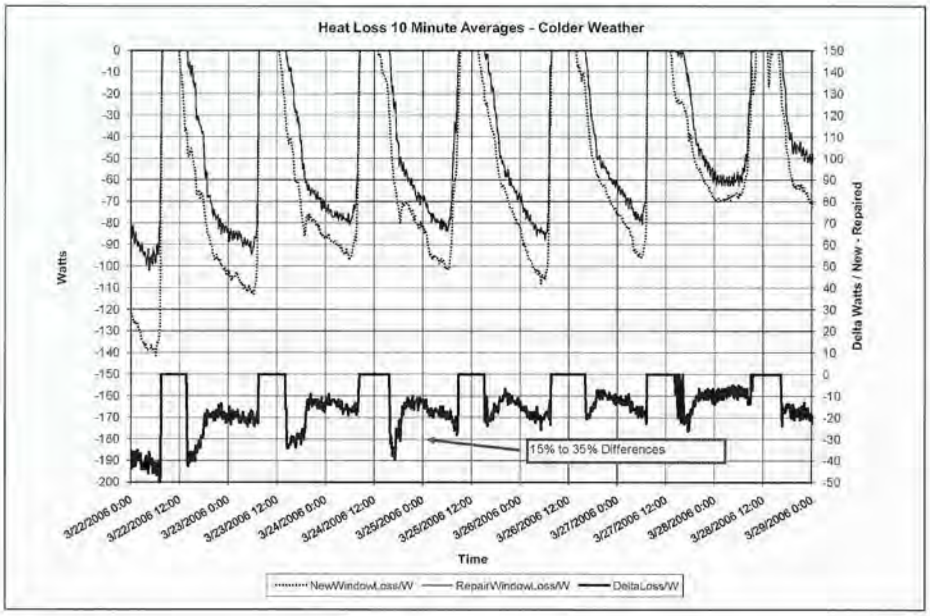

Fig. 12. Heat loss during the coldest week.

may not be applicable to north-facing windows and requires further analysis. As solar heat gains vary throughout the year, careful consideration of the comprehensive building heating and cooling loads and mechanical-system requirements are needed to optimize the gains and losses through the windows, maximizing gains when needed while minimizing losses throughout the day and the changing seasons. Additional assessment — including the evaluation of other exposures (e.g., north and south), glazing-coating options, and other factors — is required to fully develop the options and will likely impact overall design decisions. This analysis can be achieved with additional mock-ups, careful application of computer simulation, or a combination of both.

The overall result of this study does not diminish the fact that thermal performance is only a portion of the overall decision process. While the repaired window offers superior thermal performance, it will also conserve original building fabric and minimize material waste by maximizing efficient use of preexisting embodied energy. Careful evaluation of historical and architectural significance, as well as the physical condition of the windows, must also be considered, in addition to future maintenance and operation needs. For an in-depth discussion of these and other considerations, the reader should refer to the Secretary of the Interior's *Preservation Brief 13: The Repair and Thermal Upgrading of Historic Steel Windows,* by the U.S. Department of the Interior (available at http://www.nps.gov/history/hps/tps/briefs/brief13.htm). Any rehabilitation project considering similar window programs should include careful identification and evaluation of these often competing factors conducted in concert with technical analysis performed by competent professionals so that appropriate options can be evaluated and an optimal solution selected.

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Notes

1. Both window mock-ups were instrumented with temperature sensors and relative-humidity and air-temperature sensors installed within the air cavity between the storm glazing and the repaired window. Surface-temperature sensors were self-adhesive E-type thermocouples that were connected to Veriteq thermocouple loggers. Each Veriteq logger monitored the temperature of four thermocouples. Thermocouples were installed at the following locations on the interior face of the repaired window frame and the replacement window frame: windowsill frame (center), horizontal meeting rail (center), left jamb (upper left), center of glass (lower light). Thermocouples were also installed on the cavity face of the storm window at the following locations: windowsill frame (center), frame of window head (center), left jamb (upper left), and center of glass (corresponding with lower light). Two Dickson D-200 data loggers were installed within the cavity space between the repaired window and the storm. The D-200 data loggers recorded air temperature and relative humidity at the lower left and upper right corners of the cavity between the storm and the repaired window. To record ambient conditions on the building exterior and interior, two Vaisala HMP44 probes and an Omega data-logging pressure box were installed. The pressure box measured the difference in interior and exterior ambient pressure.

The window mock-ups were constructed on site to allow review of numerous features, including but not limited to appearance, constructability, cost, and impact to building tenants, as well as performance. In addition to thermal-performance monitoring, testing included air-infiltration testing in accordance with American Society for Testing of Materials (ASTM) E783: Standard Test Method for Field Measurement of Air Leakage through Installed Exterior Windows and Doors, as well as water-penetration testing in accordance with ASTM E1105: Standard Test Method for Field Determination of Water Penetration of Installed Exterior Windows, Skylights, Doors, and Curtain Walls, by Uniform or Cyclic Static Air Pressure Difference. Though not discussed in this paper, the repaired-window mock-up allowed roughly 50 percent less air-infiltration leakage than the replacement window, likely due to the operable sash of the repaired window being fixed and sealed shut with sealants and paint coatings, while the replacement window, though fixed shut, relied upon gasket seals. The repaired-window mock-up had comparable water-penetration resistance to the replacement window.

2. Since monitoring did not include barometric-pressure measurements, calculations include a constant barometric pressure of 101.325 kPa. This assumption carries through calculations for both windows and will cancel out as the

windows are compared. The humidity ratio in kg/kg is calculated using interior temperature and relative humidity. The entering- and leaving-air enthalpy is calculated in kJ/kg using the humidity ratio and respective air temperatures. The mass of the air flow is calculated using the specific volume of the discharge air in m^3/kg. The data-logger time interval is five minutes, and all kJ calculations are converted to watts by multiplying by 1,000 and dividing by 300 seconds. *American Society of Heating, Refrigerating and Air-Conditioning Engineers Handbook*, vol. 1, *Fundamentals* (Atlanta: ASHRAE, 2005).

3. The coldest temperatures recorded were approximately 32°F (0°C), observed over a span of several hours throughout the first week of data recording. The average peak wintertime temperatures are typically found by using the exterior heating design temperature for Washington, D.C., which can be found in Table D-1 of the ASHRAE Standard 90.1-2004. The exterior heating design temperature of 15°F (-9.5°C) corresponds to the 99.6 percent annual cumulative frequency of occurrence, which means that actual exterior temperatures exceed this design temperature for all but 0.4 percent of the year, or about 1.4 days, during a typical year.

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Windows: Cost & Savings of Window Rehab Choices

A recent study conducted by the University of Vermont and the CS Army Corps of Engineers Cold Regions Research and Engineering Laboratory has helped to **supply essential** data on the costs and benefits **of window replacement** and alternative **strategies.**

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 not be based primarily on energy considerations.

- 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.

  For example, replacing a conventional window and storm with a double glazed, low-e replacement window would cost from $200.00 to $500.00 and would result **in** an annual energy savings of $35.30 if the original window was tight or $20.0O if the original window was loose.

- Diagnostic whole-building **air** leakage (blower door test) should be used as a 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 should be placed in that context.

This information was compiled by Informed Energy Decisions, LCC, a company committed to helping homeowners make their homes more energy efficient, comfortable, and cheaper to maintain. http://www.energydetectives.com/

Helpful Resources

What Should I Do About My Windows
http://www.homeenergy.org/19-4.html
Window retrofit decisions will be made easier with a little help from an advisory tool.

Do it yourself Energy Audit
www.hes.lbl.gov
'Do it yourself' energy audit at the Lawrence Berkeley National Laboratory. 'Home Energy Saver' can be run in 'quick' mode, or with detailed info about your house.

SEVEN TO SAVE ENDANGERED PROPERTIES LIST, 2006:

Original & Historic Wood Windows: Repair and Preservation

PROJECT CO-SPONSORS: HISTORIC ALBANY FOUNDATION, INC. & ASSOCIATION FOR PRESERVATION TECHNOLOGY, NORTHEAST CHAPTER.

The Preservation League of New York State designated Original & Historic Wood Windows as one of the listing for the "Seven to Save Endangered Properties Program" of 2006.

Each year thousands of historic wood windows are removed and sent to landfills across New York State. Along with project partners Historic Albany Foundation and the Association for Preservation Technology-Northeast Chapter, the League has been particularly concerned about this issue because original wood windows are such an important part of the appearance and character of a historic home. Property owners should have all of the facts before they opt for replacement.

What's all the fuss about windows?

You might think that windows mainly serve as functional components of a building to provide light, ventilation and a view outside. Of course, they also impact the overall appearance of the building—just consider the effect of unpainted windows on an otherwise attractive building. And that may be why you are thinking about sprucing up the exterior of your property with new windows.

You have many options for improving the looks and function of your historic wood windows.

I'm just changing the windows and keeping the rest of the house the same.

While often seen as interchangeable parts, windows are actually one of the most important aspects of a building's original material fabric and historic appearance. The design of the windows is just as important as any other decorative element. Windows offer clues to the age of the house, demonstrate the styles or construction techniques of a region or period, reflect later changes to the building, and can be exceptional examples of craftsmanship or design. Since they are original design elements which relate to other parts of the architectural style, overall scale and proportion of a building, we say that the windows are an important part of a building's *character*.

By considering the changes in window design brought about by changes in technology and in design ideas, we can construct a timeline of window types that help us identify the original style of a house or the period during which it was updated. In the United States, the earliest windows were casement (hinged windows opening out like a door), and buildings retaining such windows were likely constructed during the earliest period of European settlement. In later revival styles they were installed to imitate the historic period. An examination of the materials themselves would help determine the age and date of the windows in each case.

As double-hung windows (with top and bottom sash) became more common in the eighteenth century, glass technology improved to produce larger panes of glass. The earliest sash commonly contained anywhere from 6 to more than 16 individual panes (also called "lights"). As the nineteenth century progressed, the industry was able to make larger panes until only two panes were used per sash or even a single pane sash became more common. At the end of the nineteenth century, as revival styles came into vogue, multiple-light and patterned sash became the norm, solely for aesthetic reasons, as technology allowed for virtually unlimited pane size. There were also stained glass windows available and affordable even for middle class homes. In addition to the number and size of panes, the shape of the window also changed over time. Certain window types are essential parts of architectural styles.

But my windows are old and junky.

In the case of wood windows, old does not necessarily mean obsolete or lower quality. In fact, given the quality of materials and craftsmanship involved in the original fabrication of your windows, they may be better than anything being made today. Windows built before the 1950s were likely constructed of milled heartwood or old-growth wood which is more dense than the woods now available. Older windows will nearly always far outlast their replacements if properly restored. In addition, traditional joinery such as pegged mortise and tenon joints used in older windows have proven to be more durable through changes in climate and moisture than are glued finger joints.

If just one part of an old wood window fails, it is easier to repair than a component in a modern window. The wood window sash can be removed from the window openings, the problem piece can be repaired and the sash reinstalled in good working order. With a modern window unit, a broken pane of glass usually requires the installation of an entirely new insulated glass unit which is not easily removed from the wood, aluminum or vinyl window members. Typically the cost for repairing the glass alone is close to the amount of a new replacement window.

When I do finally get my windows to open, I can't get them to stay in place. I'd rather have new, working windows.

Many a stubborn window can be repaired by simply replacing a cord which is broken or painted so that it no longer rolls easily along the pulley. This allows it to properly use the counter weight which not only aids in moving the window but also in keeps it in place. If you are replacing the weights, make sure that they are the right size—neither too heavy or too light—to function properly with your windows. If the cords are not the culprits, you may need to remove paint from the window or frame itself which is causing the window to stick.

I don't think there are any repairs that I can do myself.

This is the true benefit of old wood windows – they were built to be reparable. Most homeowners have the skills needed to repair old wood windows, whether the problem is a broken sash cord preventing the window from moving up and down easily or staying in place, or there is a broken pane of glass. Old window sash can be easily removed from the window openings, paint and glazing putty that has built-up can be stripped and renewed, a broken pane can be swapped out for a new pane (reglazing), the cord holding the weight can be replaced and reattached and window put back in place.

No engineering degree is necessary, and all the tools and materials needed are available at your local hardware store. Replacing the glazing putty, the glass, the sash cords, and the weather-stripping can be done at a cost equal or less than $1/linear foot. There are countless step-by-step instructions available in books or on the Internet to guide a homeowner in making these repairs. Don't be overwhelmed by trying to do all the windows at once. Try to assess which windows need which type(s) of repair and break the project down into phases. Begin with the more simple repairs. Find out whether a workshop is available in your region.

I barely know a hammer from a handsaw, and I don't know of any contractors who repair windows.

A local hardware store can easily replace a broken pane of glass within a sash (reglazing). Most contractors can do simple repairs to wood elements or reglazing. (Others may try to sell homeowners on replacement windows, where most of the mark-up is in the product, not the labor.) For larger projects, property owners can contact a local historic preservation organization which might maintain a list of contractors who work on historic buildings. Homeowners can also reach out to their municipality or state preservation office for contractor lists.

When interviewing a contractor it is important to ask for and check references. It is also a good idea to get several contractor estimates to compare. What one person says is irreparable may be another person's idea of a simple repair.

I live in an historic district and am not allowed to install storms or screens over my windows.

I don't want to have to mess with installing and removing storm windows.

Many buildings dating to the late-19th and 20th century added protection during the winter by using wooden storm windows in the North and shutters or blinds in the South. Therefore, it is absolutely historically appropriate to install wood storms over your wood windows. In fact, this added layer will protect the paint and glazing of your primary window and eliminate any drafts the weather-stripping has not stopped.

Most homeowners associate wood storms with the obligation of having to install them in the fall and remove them in the spring. This was often the case in the past, when homeowners would take that opportunity to wash the windows and touch up any failing paint. Today there are many manufacturers of traditional-looking wood storm windows that incorporate screen panels which eliminate the need to swap the storms for screens each year.

My contractor just shook his head and told me it would be cheaper to replace all the windows.

It is rare that *all* windows on a single building fail at the same time, and the most cost effective approach to windows is to repair and maintain individual windows as they need work. By definition, repair work is most often done on site by local workers and is limited to only the work needed for each individual window: One window may need only new or reset hardware while another more deteriorated needs an entire new bottom sash. One advantage of repair is that it can be easily phased to spread the work and costs over a time period, as permitted by weather and budget. One efficient way to carry out needed maintenance may be to combine the work with an exterior painting project. This will most likely require coordination between the painter and window repair specialist.

Because wood has the advantage of being repairable with readily available materials and tools, a program of repairing windows to a like-new condition, followed by periodic maintenance, is the most cost efficient long term solution. Stop and think—if only one or a few windows are in bad shape, repairing them is easier than replacing all windows in the whole house.

I was told I'd be better off with all new windows that would help me battle high heating bills.

Many property owners think they must replace their old wood windows in order to save energy. Studies have indicated that in most cases [15 to] 20% of heat loss in a building is through the windows. The remaining 80% is through walls, roofs, floors and chimneys. Following this model, reducing the heat loss through windows by 50% will only result in will only result in a 10% decrease in the overall heat loss in the building.
Replacement windows can be built using wood, vinyl, or aluminum sash, and may have single, double, or even triple glazing. It is this capacity for double or triple glazing which is thought to be more energy efficient.

However, most heat loss from a window occurs from air infiltration between the sash and the window frame. Homeowners will gain better energy efficiency by maintaining the caulk around a window and using a properly-fitting storm window (R factor 1.79), than with a double-paned replacement window (R factor 1.72). To put it a different way, according to the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE), an historic wood window with storm transfers LESS heat per square foot of material (known as U-value), than replacement windows on vinyl tracks with either a double-glazed wood sash or a double-glazed metal sash.

Replacement windows can contribute to heat loss due to the spring-loaded vinyl track along the frame. As previously stated, most air loss occurs in the space between the sash and the frame. Wood is a far superior insulating material than vinyl, particularly the dense, old-growth wood found in historic houses. New window installation, no matter what the material used for the sash, requires vinyl tracks to hold the sash and allow it to move up and down. Vinyl, which contains vinyl chloride, classified by the EPA as a Group A, human carcinogen, expands and contracts in heat and cold, and will deteriorate with sun exposure more rapidly than wood.

Because vinyl window tracks are naturally exposed to heat, cold and sun, they will degrade and eventually lose their air seal. When this happens, they must be completely replaced. Historic wood windows, which run along wood tracks with the help of counter weights, can be maintained. If the wood finally deteriorates, it can be easily repaired or replaced without having to replace the entire window. In many instances, therefore, the vinyl windows do not deliver energy savings nor last as "permanent" windows.

I was told that my historic windows aren't up to code.

Code requirements for windows are generally applied only when rehabilitation or construction projects are undertaken. One- and two-family residences are governed by the *Residential Code of New York State* which regulates various aspects. Sections:

a) *Energy Conservation*. Historic buildings are exempt from the energy conservation requirements of the code, per Section 1101.2.5.3. The code's definition of historic buildings includes those determined significant by the state or local governing body, and those listed in or determined eligible for the National Register of Historic Places. For existing (non-historic) buildings, Section 1101.1.3 of Chapter 11 identifies buildings and conditions that need not comply with the chapter's energy provisions, including when less than 50% of the building's windows are not being altered.

b) *Light and Ventilation* (Section 310.1). When windows or rooms are changed or substantially altered, windows are required to provide a minimum amount of light and ventilation for basements and habitable rooms. For light, habitable rooms must be provided with aggregate glazing area of not less than 8 percent of the floor area of that room. For ventilation, the minimum operable area is calculated as 4 percent of a room's floor area, a total of the amount provided by windows, doors, louvers or other approved openings.

c) *Emergency Egress*. Windows may also be required for emergency egress purposes. Section 310.1 requires one emergency escape opening for basements with habitable space and every sleeping room. These must have a sill height of not more than 44" above the floor, and a minimum net clear opening of 5.7 square feet (5.0 square feet for grade floor openings): minimum dimensions are 24" in height and 20" in width.

I know there is lead paint on my windows and I've heard that they are not safe.

While eliminating lead paint on windows may be required for projects funded by the U.S. Department of Housing and Urban Development (HUD), no such requirements exist for New York State homeowners undertaking work at their own houses. Lead dust can create critical health issues, especially for children, however the presence of a stable lead surface is acceptable. The key is to keep finishes in good condition, repair and repaint on a regular cycle, and avoid stripping paint unless there is evidence of real paint failure.

When stripping is determined to be necessary, the procedures outlined in the National Park Service's publication *Preservation Brief #37 Appropriate Methods for Reducing Lead-Paint Hazards in Historic Housing* will provide excellent guidance. Among the most important recommendations for dealing with lead paint:

(1) children should live elsewhere while the work is being done
(2) all existing paint need not be removed-only that required to provide a sound surface for repainting
(3) it is important to use appropriate protective gear which can be found at a hardware store
(4) clean up after every work session.

Note that wet sanding can minimize dust. Chemical strippers can present problems. In addition to the potential health concerns associated with working with chemicals, the pores of wood wet from the chemical reaction can open up and permit lead based paint to seep into the wood. You can find the Preservation Brief on the National Park Service website at:
www.cr.nps.gov/hps/tps/briefs/brief37.htm, or visit www.cr.nps.gov/buildings.htm, then go to "Preservation Briefs" No. 37.

Resources

Books and Booklets

The Repair of Historic Wooden Windows, *John H. Myers, National Park Service Preservation Brief #9. Online version in Preservation Briefs section at www.cr.nps.gov/buildings.htm or order at 866-512-1800.*

Repairing Old and Historic Windows, New York Landmarks Conservancy, 1992; www.nylandmarks.org/; 212.995.5260

Save Your Wood Windows, John C. Leeke, www.historichomeworks.com/hhw/office/consult.htm; 207 773-2306;

Windows on Preservation, John C. Leeke, William McCarthy & Ann Lawless, American Precision Museum, 2005; 802-674-5781; www.americanprecision.com

Articles

What Replacement Windows Can't Replace: The Real Cost of Removing Historic Windows*, Walter Sedovic & Jill Gotthelf, Association for Preservation Technology (APT) Bulletin, 36:4, 2005.*

"What Should I do about my Windows?" *by Bill Mattinson, Ross DePaola, Dariush Arasteh, Home Energy, July/Aug 2002, p. 24-31.*

"Wood Windows: A Guide to Repair and Replacement" *by Richard Spigelmyer, Traditional Building, Jan/Feb 1997, p. 35, 44.*

Websites:

Secretary of Interior's Standards for Rehabilitation. *Detailed guidelines on the accepted practices for various approaches to preservation work, see www.cr.nps.gov/local-law/arch_stnds_0.htm.*

www.historichomeworks.com Includes many restoration topics including windows.

www.windowrepair.com/ "A website devoted to the fine art of making old windows work like new and be energy efficient too."

The ***Old House Journal*** *has all types of information about preservation issues, restoration, history and products: www.oldhousejournal.com/index.shtml (Not to be confused with "This Old House")*

www.oldhouseweb.com/ Has a section on step-by-step window repair.

Project Co-sponsors:
Historic Albany Foundation: www.historic-albany.org
Association for Preservation Technology: www.apti.org/,
APT Northeast Chapter: www.apti.org/chapters/northeast/index.cfm

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NATIONAL
TRUST
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HISTORIC
PRESERVATION

Historic Wood Windows

A tip sheet from the National Trust for Historic Preservation

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This tip sheet on historic wood windows was developed as part of the National Trust for Historic Preservation's Sustainability Initiative.

About the Initiative:
Historic preservation can – and should – be an important component of any effort to promote sustainable development. The conservation and improvement of our existing built resources, including re-use of historic and older buildings, greening the existing building stock, and reinvestment in older and historic communities, is crucial to combating climate change.

Learn more about Preservation and Sustainability on the web:
www.preservationnation.org/issues/sustainability

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Introduction

There is an epidemic spreading across the country. In the name of energy efficiency and environmental responsibility, replacement window manufacturers are convincing people to replace their historic wood windows. The result is the rapid erosion of a building's character, the waste of a historic resource, and a potential net *loss* in energy conservation. Typically replacement windows are vinyl, aluminum, or a composite with wood, and none will last as long as the original window. Repairing, rather than replacing, wood windows is most likely to be the "greener option" and a more sustainable building practice.

Research shows that most traditionally designed wood-frame buildings lose more heat through the roof and un-insulated walls than through the windows.[1] A historic wood window, properly maintained and fitted with a storm window, can be just as energy efficient as a new window.[2] Replacing a historic single-pane window also may not save you much money in the long run. While the exact figure will vary depending on the type of window installed and whether or not a storm window is used, studies have found that it could take 100 years or more for a replacement window to pay for itself in energy savings.[3] According to information published in a recent *Old House Journal* article, it could take 240 years to recoup the cost of replacing a single-pane window-storm window combination with a low-e glass double-pane thermal replacement window.[4] Also, a historic wood window can easily last more than 100 years, while a new window may not last 25.

Not every wood window can be repaired and there are situations where replacement is appropriate. However, many historic wood windows can and should be repaired, especially if the windows were manufactured before about 1940. Wood windows made before this time were constructed with individual parts, each of which can be repaired or replaced. The wood itself is denser and of higher quality than what is grown today, and it is generally more rot- and warp-resistant than modern wood.

Historic windows are among the most important elements of a building. Simple repairs and routine maintenance coupled with storm windows make for energy efficiency that in most cases matches, if not exceeds, the efficiency of replacement windows. Workshops throughout the region have taught building owners easy ways to care for their historic windows. At the Woodlawn Museum in Ellsworth, ME, a grant from the National Trust for Historic Preservation helped fund a window repair workshop. *Photo courtesy of the Woodlawn Museum*

These are just some of the practical reasons to repair rather than replace historic wood windows. In addition, repairing the historic window helps maintain a building's authenticity. Once original material is removed from a building, it is gone forever. There are many more benefits to repairing your wood windows, so keep reading.

————————————————

1. Rypkema (2006); James *et al* (1996); Klems (2002). 2. James *et al* (1996); Klems (2002). 3. Sedovic (2005); *e.g.* research by Keith Heberern, calculations available at www.historichomeworks.com/hhw/education/windowshandout/windowenergyanalysis.pdf. 4. "Let the Numbers Convince You: Do the Math." Old House Journal 35 no. 5 (September/October 2007).

Wood Window Basics

Using this 12-over-12, double-hung wood window as our example, here are the basic terms used for wood window parts. This window is called 12-over-12 because there are 12 panes of glass in each sash. Both sashes are moveable so it is called double-hung. If only the bottom sash moves, it is called single-hung.

Jamb (the wood that frames the window opening)

Top Sash (upper section of window, may slide down to open)

Meeting Rail or **Check Rail** (the rail where the two sash come together)

Bottom Sash (lower section of window, typically slides up to open)

Sill (exterior, horizontal piece at the bottom of the window frame, commonly wood, stone, or brick)
Stool (interior shelf-like board at the bottom of a window against which the bottom rail of the sash rests)

A c. 1846 wood window in the former Robbins and Lawrence Armory, now the American Precision Museum in Windsor, VT.

Rail (horizontal part of sash)

Stile (vertical part of sash)

Muntin (horizontal, vertical, diagonal, or curved pieces that frame and provide mounting surface for the lights) The shape, or profile, of the muntin provides a clue to the window's age.[1]

Light/lite/pane (glass, held in place by glazing putty and metal glazing points)

1. Garvin (2002).

My Windows Are Old and Drafty, Why Shouldn't I Buy New Ones?

1. **More heat is typically lost though your roof and un-insulated walls than through your windows.** Adding just 3 and 1/2 inches of insulation in your attic can save more energy than replacing your windows.[1]
2. **Replacement windows are called "replacement" for a reason.** Manufacturers often offer lifetime warrantees for their windows. What they don't make clear is that 30% of the time, a replacement window will be replaced within 10 years.[1]
3. **Replacement windows that contain vinyl or PVC are toxic to produce and create toxic by-products.** Installing these in your house is not a 'green' approach.[2]
4. **If your wood windows are 60 years old or older, chances are that the wood they are made of is old growth**—dense and durable wood that is now scarce. Even high-quality new wood windows, except for mahogany, won't last as long as historic wood windows.
5. Studies have demonstrated that **a historic wood window, properly maintained, weatherstripped and with a storm window, can be just as energy efficient as a new window.**[2]
6. According to studies, **it can take 240 years to recoup enough money in energy savings to pay back the cost of installing replacement windows.**[3]
7. **Each year, Americans demolish 200,000 buildings. That is 124 million tons of debris, or enough waste to construct a wall 30 feet high and 30 feet thick around the entire U.S. coastline.**[4] Every window that goes into the dump is adding to this problem.
8. With a little bit of practice, **it can be easy—and inexpensive—to repair and maintain your wood windows.**[5]
9. Not a DIY-er? There are people near you who can do it for you. **Hiring a skilled tradesperson to repair your windows fuels the local economy and provides jobs.**[1]
10. **Historic wood windows are an important part of what gives your older building its character.**

1. Rypkema (2006). 2. Sedovic (2005). 3. *e.g.* Calculations by Keith Heberern available at www.historichomeworks.com/hhw/education/windowshandout/windowenergyanalysis.pdf. 4. Hadley (2006). 5. *e.g.* www.historichomeworks.com

Basic Maintenance

There are many good, practical books and magazine articles to guide a handy person in the basic maintenance of wood windows. Several publications are listed in the references section of this tip sheet. To get you started, here are some of the keys to many years—and generations—of life with older wood windows.

1. Keep the exterior surfaces painted, including the glazing putty. Paint protects the wood and putty from water and extends their service life. Be especially attentive to horizontal surfaces where water may collect.

2. Glazing putty will eventually dry out and is meant to be periodically replaced. You can do spot repairs initially, but eventually it will be easier to re-glaze the whole sash.

3. Keep movable surfaces, such as the inside jamb, free of paint build-up so that the sash can slide freely.

4. If your sashes are hung with cord, keep the rope free of paint. This will improve the window's operability. Cord will eventually dry out and break but can be replaced. When replacing the cord you can also re-hang the weights so that the sash will be balanced.

Winter Tips

Most of the heat transfer occurs around the perimeter of the sash rather than through the glass. So the tighter the seal around the window and between the upper and lower sash, the more energy efficient the window will be. Here are some tips to help you save on your heating bills.

Check the lock. Most people think the sash lock is primarily for security. It does help with security, but the lock's most important job is to ensure that the meeting rails are held tightly together. A tight fit greatly reduces air infiltration.

Weather stripping—add it or renew it. Adding weather stripping to your window can increase the window's efficiency by as much as 50%. It's an inexpensive way to boost your window's efficiency. There are many different kinds from which to choose. Refer to the articles listed at the end of this tip sheet. The staff at your local hardware store should also be able to assist you.

Storm windows—use them! There are many styles from which to choose, including storms that can be fitted on the interior of the window. Many studies have shown that a wood window in good condition fitted with a storm window can be just as energy efficient as the more expensive replacement window. Due to the thermal exchange properties of wood, there is also a growing interest in traditional wood-framed storm windows as they transfer less heat than metal-framed storms.

Condensation. If you find condensation on the inside of your primary window, cold air leaking through the storm window is likely the culprit. If the condensation is forming on the inside surface of the storm window, warm air from the building interior is leaking in around the primary window. When warm and cold air are present on opposite sides of glass, condensation forms (think of a cold glass of lemonade on a hot day). When condensation forms on your window glass, water can collect on the horizontal wood parts of the rails, muntins, and sill, which can lead to paint failure and rot. To reduce condensation, you need to limit the amount of leaking air. Add or replace weather stripping, make sure the sash are meeting properly and that the sash lock is tight, and check the seal around the exterior of the storm window and caulk if necessary. When caulking around the perimeter of exterior storms it is important to leave weep holes at the bottom so that any condensation or infiltration that does occur can drain out.

What About Lead?

If your windows retain paint that was applied prior to 1978, chances are there is lead paint on them. Just because there may be lead paint on the windows does not mean they are unsafe or that they need to be replaced. There are steps you can take to protect yourself and others if you suspect lead paint may be present. **Before beginning work, consult your local or state ordinance to determine the legal method for handling and disposing of lead paint in your area.**

- Children and pregnant women should not be allowed in the work area.
- Do not smoke or eat or drink in the area you are working in and wash your hands and face before doing so.
- Wear disposable gloves and eye protection.
- Use a respirator if there is friable paint, or if you are scraping or sanding paint.
- Use a wet sanding technique to minimize dust.
- Vacuum using a HEPA filter.
- Wash your work clothes separately from your household laundry. You can also wear a tyvek suit to protect your clothes. Take it, and your shoes, off before you leave your work area.
- Place tarps under your work surface to collect loose paint. Seal off the work space from other rooms and from HVAC systems. Cover any furniture and other items in the work area with

(Continued on page 4)

Lead continued

6 mil plastic taped to the floor.
- Eating a nutritious diet rich in iron and calcium will reduce the amount of lead absorbed by your body if any does happen to be ingested.
- For more tips on how to work lead-safe, see "Lead Paint Safety: A Field Guide for Painting, Home Maintenance, and Renovation Work" available at www.hud.gov/offices/lead/training/LBPguide.pdf and the National Park Service Brief #37, "Appropriate Methods for Reducing Lead-Paint Hazards in Historic Housing" at www.nps.gov/history/hps/TPS/briefs/brief37.htm.
- John Leeke's website www.historichomeworks.com also has practical tips on lead-safer work practices.

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Additional Help

With nearly half of greenhouse gas emissions attributed to the construction and operation of buildings, older and historic buildings are central to our efforts to address climate change. The **National Trust for Historic Preservation's Sustainability Initiative** promotes the reuse of existing buildings, reinvestment in existing communities, and green retrofit of older and historic buildings to help lower carbon emissions. For more information visit www.preservationnation.org.

Additional help may be available from your **State Historic Preservation Office** (SHPO). Find your SHPO at www.ncshpo.org/. Private **statewide and local preservation groups** serve as the network centers and representatives of local preservation activities within their states. The nine **Regional and Field Offices of the National Trust for Historic Preservation** (NTHP) bring the programs and services of the NTHP to preservationists within their regions. Find your nearest NTHP Regional Office and state and local preservation organizations at www.preservationnation.org/about-us/partners/statewide-local-partners/contacts.html

Testing the Energy Performance of Wood Windows in Cold Climates

A Report to
The State of Vermont Division for Historic Preservation
Agency of Commerce and Community Development

August 30, 1996

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EXECUTIVE SUMMARY

During rehabilitation of historic buildings, the question of how to treat the windows is inevitably raised. The desire to retain the historic character of the windows and the actual historic material of which the windows are made is seen as competing with the desire to improve energy performance and decrease long term window maintenance costs. Replacement of window sash, the use of windows inserted inside existing jambs or whole window replacement is often advocated in the name of energy efficiency, long term maintenance cost reduction, ease of operation, and better assurance of window longevity. Other approaches to improve the energy efficiency of historic windows retain all or part of the existing sash and balance system and typically include exterior triple-track storm window rehabilitation or replacement. Some building renovations only include storm window repair or replacement and prime window maintenance. To date there is little data quantifying the impact on annual heating costs of these varied upgrade options or comparing estimated first year energy savings to installed costs. This study was undertaken to test the assumption that historic windows can be retained and upgraded to approach the thermal efficiency of replacement sash or window inserts.

While upgrades often improved other aspects of windows, including ease of operation, reduction of lead hazard, and occupant comfort, only energy impacts were included in this study. In order to assess energy improvements due to window upgrades, it was necessary to establish first year heating energy costs associated with windows before and after upgrades. Energy costs resulting from thermal losses associated with a window are due to both infiltrative and non-infiltrative losses.

Infiltrative thermal losses through a window arise from air moving around the sash and jamb as well as through any cracks or gaps associated with the window. Thermal losses also occur due to radiation through the glazing, conduction through the window materials, and convection of the air layer next to the window materials. These latter three methods of heat loss (conduction, convection, and radiation) are considered to be non-infiltrative thermal losses and were modeled using WINDOW 4.1, a computer program simulating fenestration thermal performance.

Infiltrative thermal losses were investigated by field testing 151 windows during 1995 and 1996, primarily in northern and central Vermont. Leakage characteristics of these windows were estimated by fan pressurization. Of these 151 windows, 64 were in original condition and 87 were of various upgrades. A percentage of infiltrative exterior air was estimated during field tests based on temperature differences in the test zone during fan pressurization. Exterior air leakage was summed with sash leakage to estimate a whole window total infiltrative thermal loss rate due to infiltration. Total window leakage rates were correlated with heating season infiltration rates by using a computational model established for estimating whole building infiltration rates. Results for the 64 original windows were used to model typical, tight, and loose original condition windows. Estimated annual energy costs of these assumed windows were used to estimate first year energy cost savings for the various upgrade types.

The significance of exterior air infiltration to the total heat load of a window was observed throughout the study. Thermal loss due to exterior air infiltration can cause the thermal performance of a tight window to approach that of a loose window. The importance of reducing exterior air infiltration during any renovation was noted. Interior storm windows effectively reduced exterior air infiltration as well as reducing sash air infiltration. Exterior storm windows in good condition showed significant reductions in sash infiltration when in the closed position.

One issue in assessing energy performance of windows fitted with storms was if the storm was in the closed position during the heating season, a factor which can change the energy performance significantly. This study did not attempt to quantify how many storms were likely to be open or closed. Therefore, the assumed loose window with no storm allowed comparison of upgrades with storm windows open as well as with windows not fitted storm windows.

First year energy savings for window upgrades and estimated annual energy costs of the assumed windows were based on a typical Vermont climate (7744 degree days). Neither cooling cost savings nor changes in solar heat gain due to window improvements were addressed.

Results of testing and analysis were expressed in a number of ways including:

- effective leakage area (ELA), which may be loosely described as the size of a single orifice with similar air flow characteristics as the sum of the cracks of the window tested;
- sash air leakage rate at 0.30 inches of water pressure differential across the window, expressed in standard cubic feet per minute pre linear foot of crack, a standard value given in specifications for new windows, representing a useful point of comparison; and
- first year estimated heating cost savings compared to the three baseline original condition windows described above.

Costs of window upgrades were investigated primarily by interviewing developers of affordable housing in Vermont. Material, installation and mark-up costs are included for the window upgrades studied. Costs for upgrades were considered above those which would be required for routine window maintenance (paint, putty, caulk, and sash balance maintenance). Routine maintenance costs were considered a baseline for any building rehabilitation apart from energy upgrades. Costs for upgrades field tested ranged from a low of $75 to a high of $500. The lower cost option included sealing the top sash, installing bronze V-strip weatherstripping and sash locks, and retaining the existing prime and storm windows. If lead abatement was required for an original sash, an additional cost of $125 was added to the upgrade cost. The larger upgrade cost was for a wood window insert with double-pane insulating glass.

The findings of the study indicated the wide range of window upgrade options and installed costs resulted in annual heating cost savings that were similar. Within several types of window upgrades tested, there were examples where inappropriate application of an upgrade or an incomplete installation resulted in below average energy performance. However, when installed carefully, virtually all the options studied produced savings in a similar range.

Estimated first year energy savings per window due to field tested upgrades ranged from zero to a high of $3.60 as compared to an assumed typical window and were slightly lower when compared to an assumed tight window. Estimated savings compared to an assumed loose window ranged from $12.40 to $16.60 per window. Estimated savings increased when windows with low-e glazing were modeled using WINDOW 4.1. It should be noted that estimated first year savings as shown should be viewed solely as relative savings when compared to other upgrades within the context of the study and not actual savings realized.

The variability in estimated first year energy savings for all window upgrades was small. A comparison of estimated energy savings per upgrade to costs for upgrade materials and installation revealed energy savings were two orders of magnitude lower than renovative costs. Based on the range of estimated first year energy savings of window upgrades generated by the study as compared to an assumed typical window and those costs associated with upgrade purchase and installation, replacing a window solely due to energy considerations did not appear to be worthwhile. Estimated first year savings of upgrades when compared to an assumed loose window are significantly greater, reflecting the importance of the original window condition in determining first year energy savings. Life-cycle costs of window upgrades were not included as a part of this study and may have a bearing on the decision making process.

As a result of the similarity in savings between upgrade types and the small savings indicated when existing windows were similar in performance to a typical or tight window, the decision to rehabilitate or replace a window generally should be made on the basis of considerations other than energy cost savings. It should be noted that this decision is not clear cut. Some upgrades that retain the original sash make major sash modifications while some replacement upgrades mimic historic windows effectively. There is a continuum between replacing and rehabilitating windows where the developer must find a solution appropriate to the particular context while considering non-energy issues such as maintenance, ease of operation, historic character, and lead abatement.

The population served by the housing is another important variable in an upgrade decision. Tenant populations in rental housing have no financial incentive to close storm windows or may be unable to operate them. In such cases, the value of estimated first year savings of an upgrade may be higher than expected if double-glazing is used in the prime window.

Once the decision to upgrade or replace an existing window is made, it is important to select a strategy that not only meets the needs of the building occupants and owners but also utilizes techniques that achieve the highest levels of energy savings and occupant comfort justified by the financial constraints and financing mechanisms of the building rehabilitation project. In general:

- Window upgrades using existing sash can achieve performance indistinguishable from replacement sash but economics of the upgrade depend on the leakiness of the original window.
- If the existing window is loose, it can often be cost-effective to address this leakage, including air leakage between the window and rough opening as well as between an exterior storm window and trim. If the window is already in typical or tight condition, an upgrade is unlikely to be cost-effective regardless of the cost-benefit test used.
- If the windows have single glass, it is worthwhile considering installing a second layer, including the options of storm windows, replacement insulated glass units, energy panels and use of low-emissivity glass (low-E).

While it is tempting to compare first year energy savings to the total installed costs of a window upgrade, it should be noted that some window upgrades may be done for reasons other than energy savings. Therefore, a strict comparison of energy costs to total installed costs may not be appropriate in all cases. In addition, the time frame over which savings may be calculated can vary significantly. Developers of affordable housing, which often includes rehabilitation of historic structures, are often concerned with establishing "perpetually affordable" housing which includes decreased long-term maintenance and energy costs.

Within the decision-making process for deciding to replace or renovate an existing window, energy considerations should not be the primary criteria, but should also not be ignored. The resulting window rehabilitation strategy should result in the most comfort and appropriate degree of energy savings.

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Glossary of Terms

Actual cubic feet per minute (acfm) - the volume of air at ambient conditions passing through the fan pressurization device per unit time

Air leakage - induced air flow through a building envelope or window when using fan pressurization. Induced air flow is a measure of building or window tightness.

Effective leakage area (ELA) - the area of a round orifice with a flow coefficient equal to one, allowing an air flow equivalent to the summed gaps around a window

Extraneous air leakage (Q_e) - the volume of air flowing per unit time through the rough opening and test apparatus when under pressurization by the testing device

Humidity ratio - mass of water vapor per mass of dry air. Essentially, the mass of water vapor contained within a volume of air as compared to the mass of that air if it were dry.

Infiltration - uncontrolled air flow through unintentional openings driven by pressure differentials induced by temperature differences and winds

Infiltrative heat load - thermal losses through a window from air moving around the sash and jamb as well as through any cracks or gaps associated with the window.

Linear foot crack (lfc) - the sum of all operable sash perimeter of a window, expressed in feet

Natural infiltration - uncontrolled air flow during the heating season through unintentional openings driven by pressure differentials induced by temperature differences and winds

Non-infiltration heat load - the thermal loss due to convection, conduction, and radiation through a window

R-value - thermal resistance (hr-ft^2-°F/Btu). The steady condition mean temperature difference between two surfaces that induces a unit heat flow rate per unit area. Essentially, a measure of resistance to heat flow. R-value is the inverse of U-value.

Relative humidity - the ratio of the amount of water vapor in the air to the maximum amount of water vapor the air can hold at the ambient temperature.

Rough opening - the opening in a building envelope designed to accept a window

Sash air leakage (Qs) - the volume of air flowing per unit time through the window exclusive of any air from the rough opening during the testing period

Standard cubic feet per minute (scfm) - the volume of air per unit time passing through the fan pressurization device, converted to standard conditions for reference and comparative purposes. Standard conditions for this study were defined as:

- standard temperature - 69.4°F (20.8°C)
- standard pressure - 29.92 inches of mercury (760 mm Hg)

Standard cubic feet per minute per linear foot crack (scfm/lfc) - standardized volume of air per unit time passing through one linear foot crack of operating window perimeter

Total air leakage (Qt) - the volume of air flowing per unit time through the window system when under pressurization by the testing device

U-value - thermal transmittance (Btu/hr-ft^2-°F). The rate of heat flow per unit time per unit area per degree temperature differential. Essentially a measure of thermal transmission through window materials and the boundary air films. U-value is the inverse of R-value.

Window - includes the jamb, sash, associated hardware but excludes the rough opening and any spaces between the jamb and rough opening

Window system - includes the window, any space between the window and rough opening, and framing members that form the rough opening

Nomenclature:

ELA_s/lfc - effective sash air leakage area per linear foot crack (in^2/lfc)
ELA_{ext}/lfc - effective extraneous air leakage area per linear foot crack (in^2/lfc)
ELA_{tot}/lfc -effective whole window leakage area per linear foot crack (in^2/lfc)
ELA_{to}t -effective whole window leakage area (in^2)
Q_{nat} - natural air infiltration rate during the heating season, due to pressure differentials induced by wind speed and direction, as well as interior/exterior temperature differences (scfm)
L_{inf} - whole window infiltrative thermal loss rates (Btu/hr-°F)
L_{non} - non-infiltrative thermal toss rates (Btu/hr-ft^2-°F)
L_u - whole window non-infiltrative thermal loss rates (Btu/hr-°F)
L_{eff} - whole window thermal loss rates; infiltrative and non-infiltrative thermal loss rates combined (Btu/hr-°F)
L_{yr} - annual whole window thermal losses (Btu/yr)
C_{win} - annual energy costs per window ($)
S_{win} - annual savings per upgrade ($)

1. INTRODUCTION

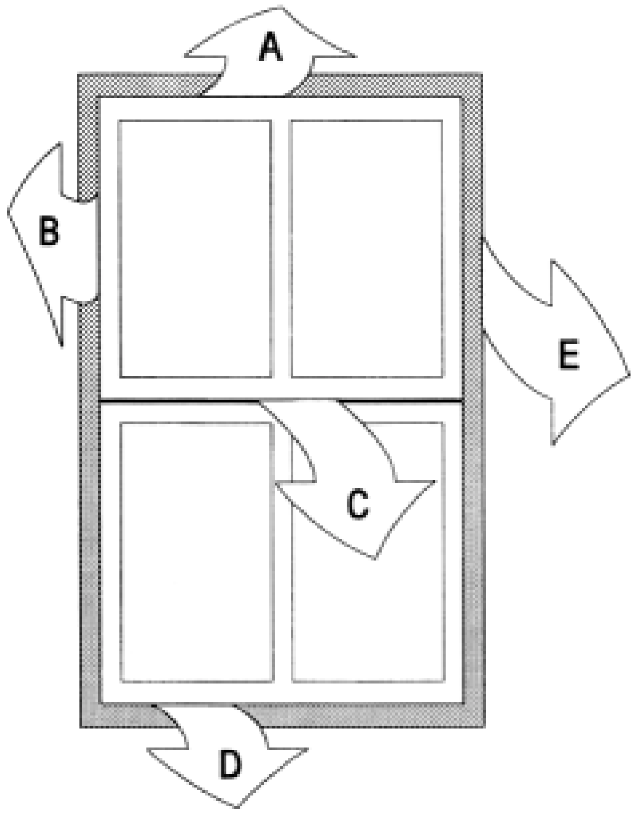
Windows serve a variety of integral roles in buildings, ranging from admitting light and ventilation to an expression of period technology and design. Windows also have a major impact on the energy consumption of a building as any thermal loss through a window must be replaced by the heating system. When historic buildings are to be renovated, the question of the existing historic windows is inevitably raised. The desire to retain the historic character of the windows and the actual historic material of which the windows are made is seen as competing with the desire to improve energy performance and decrease long term window maintenance costs. Replacement of window sash, the use of windows inserted inside existing jambs, or whole window replacement is often advocated in the name of energy efficiency, long term maintenance cost reduction, ease of operation, and better assurance of window longevity. The renovation of historic windows to improve energy efficiency retains all or part of the existing sash and balance system and typically includes exterior triple track storm window rehabilitation or replacement. To date, there is little data that quantifies the impact on estimated first year heating costs of these varied approaches or compares the estimated value of energy saved to installed costs. This study was undertaken to address the assumption that historic windows can be retained and upgraded to approach the thermal efficiency of replacement sash or window inserts. While window upgrades often improved other aspects of windows including ease of operation, reduction of lead hazard, and occupant comfort, only energy impacts were included in this study.

In December 1994, the State of Vermont Division for Historic Preservation (DHP) of the Agency of Commerce and Community Development issued a Request for Proposals to address the energy impacts of the rehabilitation versus replacement issue, based on a grant from the National Park Service and the National Center for Preservation, Technology, and Training. The study was directed toward windows in historically significant buildings, including affordable housing and private residences. Major issues addressed were:

- energy savings attributable to existing window retrofits,
- estimating first year savings in heating costs attributable to field tested window retrofits,
- installation and materials costs for existing window retrofits, and
- the comparison of costs and savings from existing window retrofits to those incurred by replacement windows.

The decision to rehabilitate or replace a window is often based on factors other than long-term energy conservation, including the historical significance of a window, its role in a building's character, occupant comfort, and ease of operation. While some of these factors were often improved during window upgrades, only energy costs associated with reduced thermal losses due to infiltration and non-infiltration were studied. Infiltrative thermal losses are due to exterior air moving through and around the sash and rough opening. Infiltrative

Figure 1: Principle air leakage sites for a typical double-hung window



A - air infiltration through the head junction
B - air infiltration through the sash/jamb junction
C - air infiltration through the meeting rail
D - air infiltration through the sill junction
E - air infiltration through and around the jamb from the rough opening

losses were investigated by field and laboratory pressurization testing. Figure 1 is a schematic diagram of a standard double-hung window, showing typical air leakage sites for that style window. Non-infiltrative losses include conduction, convection, and radiation through the materials of the window and were simulated using a computer model.

While historically significant buildings are found throughout Vermont, few were scheduled for renovations during the time frame of the study. Many affordable housing buildings and private residences in Vermont are of the same nature as historic buildings and were scheduled for, or had undergone renovations during the required time period. Due to building similarities, windows in affordable housing and private residences consequently constituted the majority of field testing with the inclusion of some historical windows renovated during the course of the study.

This report contains the results of the study implemented to determine the effectiveness of various window rehabilitations in reducing infiltrative and non-infiltrative thermal losses. Those rehabilitations included windows utilizing existing sash as well as several replacement options. The results, gathered from 151 windows at 19 sites, estimate the first year energy impacts of upgrades associated with a reduction in heating cost requirements during an average Vermont heating season. No attempts were made to estimate either the contribution of solar gains during the heating season or energy impacts associated with reductions in cooling requirements due to window upgrades.

While not addressing all issues concerning window performance and operation, the results of this study concerning the energy performance of windows during the heating season will be beneficial to the historical preservation community as well as providers and developers of affordable housing and the general home-owner. This information will allow those organizations and individuals to make better informed choices about window rehabilitation and replacement strategies based on actual data as opposed to anecdotal evidence.

2. BACKGROUND AND SIGNIFICANCE

A literature review was undertaken to determine the nature of previous work and findings relevant to the study.

2a. Whole Building Energy Losses

One of the primary purposes of building renovation is to reduce energy consumption and costs via thermal losses due to air infiltration. A large body of pre- and post-renovation data for whole building energy consumption does not exist. However, a reduction in building energy requirements may be accomplished by reducing air infiltration through sills, walls, basements, attics, doors, and windows. Estimated energy costs associated with air infiltration range from 33% of total building energy costs (Sherman et at., 1986) to as much as 40% (Giesbrecht and Proskiw, 1986). Upon completion of whole building retrofitting, reductions in energy costs attributable to infiltration have been estimated to range from 19% based on a 55 house sample (Jacobsen et at., 1986) to 50% for a single townhouse (Sinden, 1978). Most saving estimates fall between 30-37% (Giesbrecht and Proskiw, 1986; Harrje and Mills, 1980; Nagda et at., 1986). Giesbrecht and Proskiw also found two-story houses showed lower reductions in infiltration after renovations (24.4%) than single-story houses (36.9%), likely due to leakage between floors.

2b. Window Energy Losses

Of concern to this study was the portion of total house leakage attributable to infiltration through and around windows. Estimates of window contribution vary more widely than whole house leakage estimates. Two separate studies found the fraction of window leakage to be approximately 20% of whole house leakage (Tamura, 1975; Persily, 1982). An estimated 37% of the total heat loss from a house may be due to infiltration through windows and doors (Lund and Peterson, 1952), while a 20 house survey showed these sources are unlikely to exceed 25% (Bassett, 1984).

The use of a mathematical model estimated 25% of heat loss through a loose fitting, nonweatherstripped window was attributable to infiltration (Klems 1983). The modeled window was assumed to be typical of windows found in older housing. A reasonably tight double-pane window, typical of new construction, was estimated to have 12% of its thermal losses attributable to infiltration by the same model. Energy costs associated with infiltrative losses became a significant portion of total fenestration energy costs when air leakage rates exceeded 0.5 cubic feet per minute per linear foot crack (cfm/lfc) based on the Residential Fenestration (RESFEN) computer model developed by Lawrence Berkeley Laboratory (LBL), University of California, Berkeley (Kehrli, 1995). Various leakage rates at 0.30 inches of water pressure were modeled with RESFEN, then reduced to total window energy losses at 0.016 inches of water pressure, the assumed average heating season interior/exterior pressure differential. Costs due to infiltration as a percentage of total window energy costs varied from 15% at 0.5 cfm/lfc to 41 % at 2.0 cfm/lfc for a two story house, based on the RESFEN simulation.

2c. Window Weatherstripping

The intent of weatherstripping a window is to reduce the amount of air infiltrating through the sash/jamb junctions and the meeting rails. Infiltrative losses were reduced from 37% to 17% of total house thermal losses when metal rib-type weatherstripping was installed around the windows (Lund and Peterson 1952). This corresponded to an approximate 24% reduction in building energy costs.

2d. Storm Windows

The installation of storm windows, either exterior or interior, presents its own range of advantages and disadvantages. In general, properly installed new storm windows in combination with existing single-glazed windows may achieve U-values comparable to insulating glass and reduce air infiltration while lowering maintenance costs and extending the life of the window (National Park Service, 1986). Thermal transmittance (U-values) refers to the amount of heat a one foot square section of window would lose per hour for every one degree Fahrenheit temperature differential and has units of Btu/ft^2-hr-°F. Lower numerical values for thermal transmittance imply better thermal efficiency.

Disadvantages of exterior storm windows include visual obstruction of an historic window and its attendant details, while interior storm windows may increase condensation and cause moisture related problems to the primary sash. The negative visual effect of exterior storm windows may be reduced by using single lite storm sash. Interior storm windows have avoided the problem of condensation by incorporating vent holes and a sealed fit (Park, 1982). The use of interior storm windows can also reduce infiltration by reducing air movement through the sash or rough opening into the building interior. Whole house energy consumption was reduced by 12% in a test house in England fitted with interior storm windows (Rayment and Morgan, 1985).

2e. Rating New Windows

Many builders, contractors, and individuals purchasing new windows for either new construction or renovation are increasingly aware of energy considerations and choose windows based on rates of sash air leakage and thermal transmittance (U-values) as well as appearance. These ratings are provided by window manufacturers and are the results of independent testing by accredited simulation laboratories. Laboratories are accredited by the National Fenestration Rating Council, with each accredited laboratory having one or more certified simulators. Air leakage tests are conducted according to ASTM E 283-91, *Standard Test Method for Determining the Rate of Air Leakage Through Exterior Windows, Curtain Walls, and Doors Under Specified Pressure Differences Across the Specimen.* Thermal transmittance tests follow ASTM E 1423-91, *Standard Practice for Determining the Steady State Therma/ Transmittance of Fenestration Systems* (Kehrli).

For sash air leakage, test results are generally provided as cubic feet per minute per linear foot-crack (cfm/lfc) at a differential of 0.30 inches of water pressure. National standards for sash air leakage at 0.30 inches of water allow a maximum sash flow of 0.37 cfm/lfc for new windows in order to be certified (National Wood Window and Door Association, 1996).

ASTM E 1423-91 is both a complex and expensive laboratory testing process, averaging $1200 per test (Kehrli). Researchers at the Lawrence Berkeley Laboratory (LBL), have developed an interactive computer program to calculate the thermal transmittance of windows. This program, WINDOW 4.1, is based on actual window testing following the E 1423-91 method and is consistent with the rating procedure developed by the National Fenestration Rating Council (NFRC 100-91: *Procedure for Determining Fenestration Product Thermal Properties).* Test data listed by window manufacturers are the results of WINDOW 4.1, the LBL computer simulation program. Manufacturers provide a random sample of their higher and lower end window models to the accredited testing laboratories to ensure actual compliance with certifiable specifications (Weidt).

2f. Window Performance

Should a renovation project be designed with replacement windows, it is likely that windows will be chosen based on the results of the manufacturers' data. The maximum 0.37 cfm/lfc allowable sash flow for certification is often exceeded by windows, as shown by both field and production-line testing (Kehrli, 1995). An on-site study of window leakage rates was done in the Minneapolis/St. Paul metropolitan area, comparing listed air leakage rates of 192 windows to actual measured leakage rates after installation in new residential constructions. Window models from sixteen manufacturers were tested, which included both double- and single-hung windows. Of all the window tested, 60% exceeded the manufacturers' listed performance specifications while 40% exceeded the 1979 industry maximum of 0.50 cfm/lfc for certifiable windows. More specifically, 79% of double-hung and 100% of single-hung windows exceeded the manufacturers' lab data. Installation technique, as performed by the various contractors, showed no significant effect on window performance (Weidt, 1979).

The Weidt study also showed double-hung windows had lower air infiltration rates per linear foot crack than did single-hung windows within any manufacturer. Infiltration rates expressed as cfm/lfc may be a misleading statistic when comparing different window types. As an example, a typical double-hung window has approximately 70% more operable linear crack per sash area than a single-hung window of identical size. If the two windows show equal air leakage rates per linear foot crack, more air is actually moving through the double-hung window due to its larger operable linear crack perimeter. When infiltration is expressed as cfm/sash area or cfm/ventilation area, single hung windows outperform double hung windows (Weidt, 1979).

2g. Non-infiltrative versus Infiltrative Thermal Losses

Within the confines of how the predominant energy loss of a window occurs, there is some debate. Those advocating non-infiltrative thermal losses being much greater than infiltrative losses, recommend all single-glazed sashes be replaced with double-pane insulating glass (Kehrli). Energy losses due to direct heat transmission through a window were observed to be consistently greater than those due to air leakage, regardless of the leakage rate considered (Klems, 1983). In a comparison of energy requirements between a test house and an idendical control, it was estimated that replacing single-glazing with double-glazing reduced losses via thermal transmission such that building space heating requirements were reduced by 9% (Rayment, 1989).

If double-pane insulating glass is to be used and the original sash retained, there must be adequate wood thickness to accommodate the rabbeting necessary to insert thicker, double-pane glass. The wood must also possess the strength to support the extra weight (National Park Service, 1986). This has been done in some old single-lite sash but presents a more complicated problem in multi-lite sash where muntins are present. As compared to a single-lite window, the larger glass/wood edge perimeter of a multi-lite window will reduce the thermal improvements of double-pane insulating glass by allowing more conduction through the edges.

Others believe that air infiltration is a larger contributor to poor energy performance than single-glazing and any steps taken to reduce infiltration are nearly always cost effective (National Park Service, 1986). The Colcord Building in Oklahoma City reduced its space heating costs by 25% when its loose fitting, single glazed windows were renovated. Renovation included reglazing with new putty compound, painting, bronze V-strip spring weatherstripping, and the addition of removable interior acrylic storm panels (Park, 1982). It was undetermined what fraction of heating cost reductions were attributable to the interior storm window and what fraction arose from the other renovations.

The addition of acrylic storm panels in the Colcord Building constituted a second glazing layer which served to decrease non-infiltrative losses through the windows. Acrylic panels were chosen over glass due to weight considerations, but provided the additional benefit of decreasing non-infiltrative losses by 15% as compared to ordinary glass storm panels. Storm windows in general provide a second glazing layer, reducing non-infiltrative thermal losses. Exterior storm windows provide the additional benefit of lowering window maintenance costs as well as prolonging window life by preventing accumulations of moisture (Fisher, 1986).

2h. Air Infiltration through the Rough Opening

A significant source of infiltration may be the gap between the rough opening of the building and the frame of a window unit (Flanders et al, 1982). Estimates of infiltrative contributions through window rough openings range from 12% of whole building energy loads in loose construction (typical of affordable housing stock) to 39% in tighter construction (Proskiw, 1995). Air leaking through the rough opening/frame juncture around an otherwise tight window will adversely affect the overall performance of the window unit (Louis and Nelson, 1995). The conventional method used to seal this gap in new construction is to insert fiberglass insulation between the rough opening and frame, even though fiberglass insulation is not intended to be an air barrier material. A laboratory study in Winnipeg, Canada, showed the conventional sealing method still allowed significant air leakage through the rough opening (Proskiw, 1995).

The amount of air attributable to leakage through the rough opening was estimated for both loose and tight houses. A loose house was assumed to have 5 ACH_{50} (5 air changes per hour at 50 Pa, or 0.20 in. H_2O), typical of older houses. A tight house was assumed to have 1.5 ACH_{50}. Ratios of rough opening to whole house leakage were based on laboratory results, which gave estimates of 14% rough opening leakage for tight houses and 4% for loose houses. The two most efficient and cost effective methods for sealing rough openings were low expansion urethane foam and casing tape, reducing estimates of rough opening leakage to less than one percent of whole house leakage (Proskiw, 1995). Casing tape is the tape normally used for taping joints between exterior sheets of insulated sheathing.

Older buildings often do not have any barrier between the frame and rough opening, allowing air access to the window unit with little impediment. Proskiw estimated 39% of total house air leakage was from rough openings in a loose house typical of older construction. The most effective means of reducing extraneous leakage require removal of both interior and exterior trim. Trim removal provides exposure and access to the window frame/rough opening junction, allowing thorough sealing. Care must be taken when using expandable foam to prevent overfilling, which could lead to window jamb distortion. It is possible to drill small holes in the jamb to insert foam, but three potential drawbacks exist. Insertion holes may be visible, but more importantly, there is a greater risk of overfilling the cavity with foam, which would cause distortion of the jamb. A complete seal also cannot be ensured without visual inspection. Removal of the trim provides this opportunity.

2i. Air Infiltration and Relative Humidity

Relative humidity plays a significant role in infiltration through old wooden windows by influencing the fit of the sash to the frame. The physical change in wood dimensions as wood absorbs or releases atmospheric moisture affects the gap dimensions between the sash and frame, directly influencing infiltration. Temperature also affects wood dimensions but relative humidity is a more important factor than wood temperature, with cold wood expanding more from absorption of outside moisture than from temperature changes (Lstiburek). While cold air in the winter does not carry a large amount of moisture, its relative humidity is approaching saturation due to the decreased amount of moisture the cold air may hold. This implies that some moisture absorption may occur in the winter with a corresponding degree of swell.

2j. Routine Maintenance

Significant reductions in infiltration may be accomplished by routine maintenance of an existing window while improving its integrity. Routine maintenance includes removing the glass, applying back putty, reinserting the glass, repointing and reglazing. Excess paint should be removed and any necessary sash or frame repairs done along with the installation of good quality weatherstripping (NPS, 1986). Repainting the sash, frame, and glazing will help provide a good seal against the elements.

2k. Benefits of Renovating Historic Windows

The advantages of renovating existing windows versus replacement in an historic building include saving the historic value and design of the window as well as the interior/exterior appearance. For these reasons, it is advantageous to investigate methods of rehabilitation in an historic building. It has been shown in both the Colcord Building in Oklahoma City (Park, 1982) and the Delaware Building in Chicago (Fisher, 1985) that effective window rehabilitation can be accomplished at a lower cost than replacement windows while still resulting in significant energy savings.

3. ASSUMPTIONS AND TYPICAL PARAMETERS

Excessive natural infiltration may lead to a number of unwanted effects and problems in a building during the heating season. The addition of cold, infiltrative air represents an additional heat load for the building, unnecessarily increasing annual energy costs. Drafts from infiltrating air affect occupant comfort levels near windows or may preclude the use of entire rooms. Older buildings are subject to low relative humidity levels due to excessive infiltrative exterior air during the heating season. Exterior air has a low humidity ratio (mass of water vapor to mass of dry air), even though it has a high relative humidity. When the exterior air is heated, humidity ratio remains constant but relative humidity drops precipitously, giving rise to dry air.

As cold exterior air infiltrates a building during the heating season, warm interior air extiltrates through wall and window openings as it is displaced. As the warm air passes through the building shell, temperature decreases and condensation may occur in insulation or on structural elements. Condensation decreases the insulative value of insulation and may lead to wood rot.

Specific areas this study addressed include the following:

- energy savings attributable to existing window retrofits,
- estimating first year savings in heating costs attributable to field tested window retrofits,
- installation and materials costs for existing window retrofits, and
- the comparison of costs and savings from existing window retrofits to those incurred by replacement windows.

First year energy savings achieved by upgrading existing windows were estimated as the difference between energy costs attributable to an assumed pre-treatment window and those attributable to a window upgrade.

An estimate of typical heating season energy costs had to be made in order to estimate savings realized from any type of window upgrade. This necessitated the definition of a building typical of affordable housing from which a base-line estimate of annual energy costs could be made. The windows in such a defined building were also to be typical of existing window stock. Although the focus of the study was to be residential historical windows, the decision was made to base estimated energy costs on a typical building used for affordable housing. The reasons for the decision were twofold - few historical windows were scheduled for renovation during the period of the study and affordable housing stock was representative of many Vermont residences, including many historical structures.

The relationship between thermal losses through typical windows to total house energy costs was of concern in order to simplify these calculations. If a reduction in thermal loss through a single window due to energy improvements correlated directly to a reduction in whole building annual heating cost due to a window upgrade, then savings could be modeled for each window upgrade directly. If this were not the case, then a whole building simulation utilizing each upgrade type would be required. This required development of a typical building for the purposes of the study.

Air leakage characteristics through typical windows were based on pressurization field testing of 64 existing windows in older buildings and homes. These data were extrapolated to 0.016 inches of water pressure and correlated to natural infiltration rates using the Lawrence Berkeley Laboratory (LBL) correlation model.

For whole buildings, pressurization data in terms of effective leakage area (ELA) is correlated to natural infiltration by a fluid mechanical model developed by the Lawrence Berkeley Laboratory. The LBL model uses a whole building ELA and a calculated coefficient to determine the seasonal average infiltration rate of a whole house (Grimsrud et al., 1982). This coefficient, specific to both house and climate, is the average heating season infiltration per unit ELA. Knowing the average seasonal infiltration rate, heating degree days for the climate, heating system efficiency, and the cost of fuel allows an estimation of the heating costs attributable to the building.

For the purposes of this study, the use of the LBL model was modified by using data from a single window rather than whole house data. The assumption was made that when using a window ELA, the results of the LBL model would have the same equivalent significance in predicting the average annual heating season natural infiltration rate for a window as the model would have when using a whole building ELA to predict the heating season natural infiltration rate for the building. It is recognized that this was not the intent of the model and as such, none of the derived values should be treated as absolutes. Rather, numbers should be viewed only as relative values and used solely for comparative purposes with other values similarly derived in this study.

A potentially significant source of thermal loss due to air leakage was around the window frame by way of the rough opening. The thermal loss may be of sufficient magnitude to significantly affect the thermal performance of an efficient window. A new test methodology cited in the literature has been proposed to segregate and quantify the amount of extraneous air leaking through the rough opening into test chamber and window surround components (Louis and Nelson, 1995). The proposed methodology does not quantify the exterior air included in the extraneous air volume, but suggests several methods to estimate the exterior air volume.

One of the outcomes of the current study was a field method used to quantify the percentage of exterior air contained in the induced extraneous air during pressurization testing. A simple method of estimating the volume of exterior air passing through the rough opening during fan pressurization is presented, based on temperature differentials. The method, implemented in the spring of 1996, required an interior/exterior temperature differential and could only be applied during the pressurization testing of 33 windows due to a limited number of available interior/exterior temperature differentials.

Once a base-line estimate was established, first year energy costs associated with upgraded existing windows or those associated with replacement sash or window inserts were estimated based on field testing and computer modeling. These estimates were based on the air leakage and thermal transmission characteristics of field tested window upgrades or replacements.

3a. Typical Affordable Housing Parameters

As previously mentioned, a typical affordable housing building was used to estimate energy costs although the focus of the study was on residential historical windows. Affordable housing provided a pool of old windows scheduled for renovation during the time frame of the study and was also representative of many Vermont residences. Affordable housing may be found in all manner of buildings, but in Vermont, these buildings generally are two story structures with both an attic and basement. The following criteria were chosen to characterize a typical, historical affordable housing building:

- 30 by 50 foot rectangular building with a gable roof;
- two heated stories with an unheated attic having R-1 9 insulation;
- uninsulated basement, heated only by losses from the heating system and floor above;
- uninsulated basement walls, exposed 2 feet above grade;
- wood frame 2 x 4 walls, uninsulated;
- eight windows on each 50 foot side, four on each 30 foot side for a total of 24 windows;
- two wooden doors, 3 ft. x 6 ft. 8 in., without storm doors;
- oil-fired heating system, 65% efficient;
- 6,100 cfm infiltration rate at 0.20 in. water pressure (50 Pa), equivalent to an average 1.2 air changes per hour during the heating season; and
- leakage areas equally distributed between the walls, floor, and ceiling.

It was assumed for this study that the building would be renovated at the same time as the windows. Assumed typical post-renovation building parameters are listed below:

- walls insulated with 4 inch cellulose;
- attic floor insulated to 12 inch settled depth (R-38);
- storm doors installed;
- infiltration rate reduced to 2,200 cfm at 0.20 in. H_2O (50 Pa) equivalent to an average 0.41 air changes per hour during the heating season; and
- heating system upgraded to 75% annual efficiency.

3b. Typical Parameters for Existing Windows

Typical windows found in affordable housing buildings were assumed to be double-hung and fitted with aluminum triple track storm windows. These windows were assumed to be single-glazed with dimensions of 36 by 60 inches, yielding 19 perimeter feet of operable linear crack. Sixty-four original condition windows were field tested for air leakage by a fan pressurization device prior to any retrofits. From these data, air leakage rates for a “typical” original condition window as well as both “loose” and “tight” windows were determine

A typical window was assumed to have an aluminum triple track storm window in the closed position. Air leakage characteristics of the typical window were assumed to be equivalent to the averaged sash leakage of all the original condition windows tested when storm windows were closed. Thermal transmission characteristics were based on wooden sash and single-pane glass. The tight window was also assumed to have a storm window in the closed position but had leakage characteristics equivalent to one standard deviation low than the field test average for windows with storms closed. The loose window was assumed to have no storm in place with leakage characteristics equivalent to the averaged sash leakage for original condition windows with storms in the open position. In all cases, a percentage of the appropriate averaged induced extraneous air was included with the sash leakage to account for the exterior air contribution.

3c. Original Condition Windows and Window Upgrades Field Tested

For the study, 151 windows at 19 sites were field tested, with 87 of those windows being various upgrade types. Sites for pressurization testing were chosen by availability, timing of scheduled renovation, suitability as to window and upgrade type, and window accessibility. Several buildings were not typical of affordable housing, but all field tested windows were representative of windows found in affordable housing throughout Vermont

Table 1 is a site list of windows field tested, showing the number of original condition windows and/or the number of upgrades tested at each site. Not all windows at a given site were tested due to accessibility or weather conditions, nor were all original condition windows retested after renovation. Occupancy and weather precluded retesting windows at some sites, while many other sites did not receive the expected upgrade within the allotted time frame of the study. Renovations sufficiently improved leakage characteristics of windows at several sites to allow a greater number of upgraded windows to be tested Also included in the last column are the number of windows tested prior to and post renovation at relevant sites.

A variety of window upgrades were field tested, ranging from minimal weatherstripping to replacement window inserts. Some windows had new aluminum triple track storm windows installed while others retained the existing storm windows. Still others used interior storm windows as an upgrade option. In two instances, existing wooden storm windows were weatherstripped and retained. Table 2 lists locations and identification numbers of sites where window upgrades were tested as well as the various upgrades encountered.

Table 1: Site locations and ID's, showing numbers of original windows and upgrades tested

Site ID	Location	Original Windows	upgraded Windows	Windows Tested Pre- and Post-Upgrade
1	CVCLT Montpelier, VT	3		
2	40 Nash Street Burlington, VT	3	3	3
3	133 King Street Burlington, VT	9	4	3
4	Congress Street Morrisville, VT	5		
5	204 Pearl Street Burlington, VT	8		
6	101 Fairfield Street St. Albans, VT	4	6	3
7	Sapling House Island Pond, VT	12	20	12
8	127 Mansfield Avenue Burlington, VT	6		
9	6 Raymond Street Lyndonville, VT	6		
10	124 Federal Street Salem, MA	4	4	4
11	76 Pearl Street St Johnsbury, VT		6	
12	12 Summer Street Morrisville, VT		10	
13	George Street Morrisville, VT		10	
14	Kidder Hotel Block Derby, VT		6	
15	4 Occom Ridge Hanover, NH	4	4	4
16	Irasburg Town Hall Irasburg, VT		7	
17	605 Dalton Drive Fort Ethan Allen Colchester VT		3	
18	Brisson Residence South Hero, VT		2	
19	40 Barre Street Montpelier, VT		2	

Table 2: Window Upgrades

ID	Location	Upgrade
2	40 Nash Street Burlington, VT	**Bi-Glass System:** Existing sash routed to accept sealed double-pane insulating glass and vinyl jamb liners. Bulb weatherstripping at meeting rail, head, and sill junctions.
3	133 King Street Burlington, VT	**Broscoe Replacement Sash:** Single glazed, wood replacement sash with vinyl jamb liners. New aluminum triple track storm windows, caulked around frame.
6	101 Fairfield Street St. Albans, VT	**Custom Gard:** Vinyl frame and sash insert with vinyl replacement sash, installed inside existing jamb. Double-pane insulating glass.
7	Sapling House Island Pond, VT	**19 Original Sash Retained:** Sash routed to accept Caldwell DH-100 or 200 vinyl jamb liners. Bulb weatherstripping at meeting rail, head, and sill junctions. **Weather Shield:** One custom Shield replacement window.
10	124 Federal Street Salem, MA	**Storm Windows:** Interior storm; aluminum triple track storm; low-profile, non-track, removable pane storm; new wooden storm window with primary sash weatherstripped.
11	76 Pearl Street St. Johnsbury, VT	**Weather Shield:** custom Shield replacement wood frame and sash insert, installed inside existing jamb. Double-pane insulating glass.
12	12 Summer Street Morrisville, VT	**7 Original Sash Retained:** Sash routed to accept Caldwell DH-100 vinyl jamb liners. **3 Marvin Replacement Sash:** Single-pane, wood replacement sash.
13	George Street Morrisville, VT	**8 Original Sash Retained:** Sash routed to accept Caldwell DH-100 vinyl jamb liners. Bulb weatherstripping at head and sill junctions. **2 Marvin Replacement Sash:** Single-pane, wood replacement sash.
14	Kidder Hotel Block Derby, VT	**Original Sash Retained:** Windows reglazed and painted. New Harvey aluminum triple track storm windows caulked to exterior trim.
15	4 Occom Ridge Hanover, NH	**Original Sash Retained:** Interior plexiglass storm windows held by magnetic strips.
16	Irasburg Town Hall Irasburg, VT	**Original Sash Retained:** Caldwell coiled spring balances; bulb weatherstrip at sill junction. Wooden storm windows felt weatherstripped. **Weather Shield:** One custom Shield replacement window.
17	605 Dalton Drive Fort Ethan Allen Colchester VT	**Original Sash Retained:** Pulley seals; zinc rib-type weatherstripping along jamb; metal V-strip at meeting rail. Top sash painted in place. New aluminum triple track storm windows caulked to exterior trim.
18	Brisson Residence South Hero, VT	**Marvin Tilt Pac:** Double-pane insulating glass replacement sash with vinyl jamb liners utilizing existing frame.
19	40 Barre Street Montpelier, VT	**Original Sash Retained:** Top sash painted in place; bronze V-strip weatherstripping; old aluminum triple track storm window frame caulked in place.

4. METHODOLOGY

Energy costs associated with existing windows in older housing must first be known in order to estimate savings from any type of window retrofit. Thermal losses accounting for these costs are attributable to natural infiltration through and around the window unit and non-infiltrative losses. Field testing and computer simulations were used to estimate associated energy costs due to infiltrative and non-infiltrative thermal losses.

A total of 151 windows at 19 sites were field tested for air leakage. These windows included 64 original condition windows used to determine base estimates for air leakage through assumed typical, tight, and loose windows. The remaining 87 windows consisted of a variety of window upgrades, ranging from minimal weatherstripping of the original window to the addition of new storm windows to total window replacement. Three windows in one location were tested over a period of eight months to investigate the correlation of air infiltration rates to environmental parameters. Laboratory tests were also performed on two original condition windows. Testing was repeated on one laboratory window after routine maintenance and on the other after an upgrade.

4a. Contribution of Window Thermal Losses to Whole House Losses

Energy losses attributable to windows account for approximately 20% of whole house losses according to the literature. One of the goals of this study was to assess a change in whole house energy consumption on a per window basis due to a window upgrade. This required knowledge of how the cost of thermal losses due to windows affected the cost of whole house losses. Calculations of energy savings could be simplified if the relationship was additive such that a decrease in energy costs for a window directly corresponded to an equivalent decrease in total building energy costs. Simplifications would arise from calculating savings based solely on energy cost reductions realized through window upgrades rather than modeling whole building performance for each type of window upgrade. The concept of an additive relationship for thermal loss is supported when leakage rates are expressed in terms of effective leakage area (ELA). Individual building components may be added together as ELA's to estimate a total building leakage area (Proskiw, 1995).

The relationship between window and whole house annual heating costs was investigated by utilizing two models, an ASHRAE static heat load model and REM/Design, a static model that estimates contributions of internal and solar heat gains. Based on surface area, actual blower door test data for both a tight and loose house were scaled to the assumed typical affordable housing building. The assumption was made that air leakage is proportional to surface area as increased surface area should allow for more leakage sites.

Both models were run with typical, tight, and loose windows in both loose and tight building configurations. Values for annual heating energy costs varied between the two models, but the incremental changes between window conditions were similar. Based on the similar incremental results of the two models, it was assumed that a reduction in energy costs due to window upgrades corresponded to an equivalent reduction in whole house energy loss.

The relative locations of leakage sites may play a large role in determining whether natural infiltration is the primary result of wind or temperature induced infiltration. Wind induced pressures would be the dominant driving force for infiltration if most leakage sites were located in the walls of a building, as opposed to floors or ceilings. If that were the case, solely upgrading the windows to reduce air leakage would transfer a greater percentage of whole house leakage to floors and ceilings. The effect of this change in relative leakage location was investigated by running the Lawrence Berkeley Laboratory (LBL) correlation model, using typical Vermont temperature and wind speed data. Using the blower door data, tests with leakage sites relegated to varying percentage locations in walls, floors, and ceilings were run for loose and tight house configurations, as well as the scaled up buildings. It was found that relative location of leakage sites had little bearing on the results with an extreme case showing a difference of 4%. Distribution of leakage sites prior to modeling a window upgrade were assumed to be even for the purposes of this study (33% ceiling, 33% floor, 34% walls).

4b. Infiltrative Thermal Losses

Losses due to natural infiltration through a window are the result of interior/exterior temperature differentials and wind induced pressure. Natural infiltrative losses were estimated from measurements of air leakage at a set range of pressure differentials. These data were the results of field testing existing window stock based on a modification of ASTM E 763-93, *Standard Test Method for Field Measurement of Air Leakage Through Installed Exterior Windows and Doors.* The modification arose from the leakiness of the original window stock. Current industry standards list air leakage rates at 0.30 inches of water pressure, the recommended reference pressure cited in ASTM E 783-93. Many original windows were in poor condition, precluding the attainment of 0.30 inches of water pressure. A range of pressures was systematically employed to characterize the leakiness of the windows according to the flow model:

$$Q = c\Delta P^{X}$$

where

Q = air flow rate
c = leakage constant
ΔP = pressure differential
x = flow exponent

Linear regression was used to determine the leakage constant (c) and flow exponent (x) for a window, based on leakage results from fan pressurization. These data were used to extrapolate air leakage rates at 0.30 and 0.016 inches of water. The latter pressure (0.016 in. H_2O) was assumed to be the average heating season interior/exterior pressure differential that drove natural infiltration. The driving force resulted from pressure differences induced by building interior/exterior temperature differentials and those from wind speed and direction. The effective leakage area (ELA) was used to characterize the total air flow moving through all openings and was calculated at 0.016 inches of water (ASTM E 779-87, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization).* The ELA is equivalent to the area of a round orifice with a flow exponent equal to one, allowing the same total air flow as the window under a driving pressure differential of 0.016 inches of water. Using an ELA value allowed air openings in and around a window to be expressed as one total area for comparative purposes.

Pressurization data in terms of effective leakage area (ELA) was correlated to natural infiltration by the fluid mechanical model developed by the Lawrence Berkeley Laboratory. As stated previously, for the purposes of this study use of the LBL model was modified by using data from a single window rather than whole house data. It should be repeated that this modification was not the purpose for which the LBL correlation model was designed and any results should not be viewed as absolutes. Values obtained from this modification should be used only for comparative purposes with other values in this study.

A portable air test unit, manufactured by DeVac, Inc., was used to induce pressure differentials testing. The unit is a self-contained device, consisting of a blower motor capable of producing an approximate air flow of 40 cfm, low (1.2-11.6 cfm) and high (10-80 cfm) volume Ametek flow meters, and a Dwyer slant-tube manometer used to measure pressure differentials. The unit may be used to produce a positive or negative test pressure. An earlier study of 196 houses showed no systematic difference between pressurization and depressurization although significant uncertainty was associated with any individual measurement (Sherman et al., 1986). A negative test pressure was chosen for the purposes of this study, primarily for safety considerations. Any pressure induced glass breakage would have been directed inwards toward the interior plastic sheet.

4b i. Fan Pressurization Test Method Description

Plastic sheeting was taped to the inside trim of a latched window if an operable latch was in place and a series of negative pressures were applied. The amount of air flowing through the window unit was read from a flow meter calibrated in cubic feet per minute. The pressures applied ranged from a low of 0.03 inches of water pressure (equivalent to an approximate 8 mph wind impacting the building) to a high of 0.30 inches of water pressure if attainable (an approximate 25 mph wind). The applied negative pressure was uniform across the entire window so that each square inch was subjected to the same pressure.

The first set of readings represented the total flow (Qt) of air passing through the window unit (through and around the sashes, jambs, and frame). A second sheet of plastic was then taped to the exterior trim of the window and the same pressure range was again applied to the window with corresponding flows recorded. The second set of readings was the extraneous flow (Q_0) and represented the air flow moving through the rough opening, frame, and jamb as the exterior sheet of plastic had isolated the area of the window within the jamb from any air passage. The difference between these two sets of readings was the sash flow (Q_5) and represented the amount of air passing through the sash area within the jamb (the area referred to in this report as the window):

$$Q_t - Q_e = Q_s$$

If the window was fitted with a working storm window, the procedure was repeated with the storm window in place.

4b ii. Environmental and window parameters recorded

Interior/exterior temperatures and wind direction were recorded on-site for each window as per ASTM E 783-93. Also estimated and recorded on-site were wind speeds based on the Beaufort Wind Scale. Barometric pressures were read and recorded in Burlington, VT. Relative humidities were determined using the on-site interior/exterior temperatures and psychrometric charts. Recorded also were various window dimensions (height, width, sash depth, etc.), window type (double- or single-hung; pulley- or pin-type), condition and location of any locking mechanism, window orientation, and weather conditions for some of the latter tests where exterior air percentages were being determined. Appendix C shows a field data sheet used for each window.

Left- and right-hand side gaps between the lower sash and jamb were measured as well as the distance the lower sash moved forward and backward at the meeting rail. Sash and meeting rail gaps were not measured for all original windows tested, as these measurements were deemed important after field testing began. For existing windows utilizing vinyl jamb liners as an upgrade, the distances between the sash/jamb liner bulb and the sash/jamb liner wall were measured on both sides of the lower sash.

It was an early goal to derive a means of visually examining a window and deciding whether to replace or upgrade without resorting to pressurization testing. As a means towards that end, original windows were characterized by their general physical condition, utilizing a twelve parameter check list (Appendix C). These twelve parameters were reduced to several combination parameters, descriptive of the physical condition of the window. Two individual parameters were also investigated for significant correlations to air leakage. Combination parameters were weighted toward meeting rail and sash fit characteristics rather than glazing condition. It was assumed that any type of window renovation would include repair of existing glazing problems.

Along with the reduced physical descriptive parameter, window type was investigated for potential correlation with air leakage characteristics. Windows were categorized as single or double-hung, and as pin- or pulley-type windows for further clarification.

4b iii. Determination of percent exterior air in Q_e

The method described above and used for this study failed to account for exterior air infiltrating through the rough opening. Infiltration of exterior air not only occurred through the window sash and sash/jamb junction (Q_s), but also through the rough opening (Q_e), adding to the heating load. The amount of exterior air through the rough opening can have a significant effect on the infiltrative heating load of a tight window, where Q_5 alone showed a small heat load. Determination of the amount of exterior air through the rough opening was therefore important.

A rough estimate of the volume of exterior air coming through the rough opening was calculated by knowing the exterior and interior air temperatures as well as the test chamber temperature (the temperature between the two sheets of plastic) while performing the test for extraneous air (Q_e). Knowing these three data points and any measured value of Q_e, a mass balance on temperature and air flow was performed to estimate the volume of exterior air in Q_e. The volume of exterior air in °e was determined by the following formula:

$$Q_{ext} = Q_e * \left[\frac{(T_{win} - T_{int})}{(T_{ext} - T_{int})} \right]$$

where:

Q_{ext} = the volume of exterior air (acfm)
Q_e = the volume of air chosen from Q_e test data (acfm)
T_{win} = the temperature between the two plastic sheets during the test (°F)
T_{int} = ambient interior air temperature (°F)
T_{ext} = ambient exterior air temperature (°F)

The volume of exterior air (Q_{ext}) was converted to a percentage by dividing through by Q_e.

This method of estimating the volume of exterior air entering the test zone during testing periods has limitations and values thus derived should not be assumed to be accurate. No attempt was made to determine the actual air path of air as it entered the wall cavities while a window was under pressure. Exterior air likely increased its temperature and reached some equilibrium as it passed through walls warmer than the ambient exterior atmospheric temperature, raising questions as to the accuracy of the temperature readings in the test zone. The method was used to determine a rough approximation of the contribution of exterior air to the overall heating load.

Estimates of the amount of exterior air entering a window as a percentage of extraneous air were made for 33 upgraded windows. Thirty-one of these windows retained the original sash with the other two being in-kind replacement sash with vinyl jamb liners. Based on the 33 windows, an averaged percentage of exterior air was calculated. This was multiplied by the average rate of induced extraneous air for each assumed and upgraded window type. This resulting rate of induced exterior air was added to the sash infiltrative rate measured while using the ASTM E 783-93 modification to provide a total infiltrative thermal loss for a window.

4c. Non-infiltrative Thermal Losses

Non-infiltrative thermal losses were determined from simulations based on the computer model WINDOW 4.1 developed by the LBL Windows and Daylighting Group. User variable window parameters include window size and type, sash material, and type of glass among other parameters. The program calculated window thermal performance in terms of U-values (thermal transmittance), solar heat gain coefficients. shading coefficients, and visible transmittances. Only U-values were used for purposes of this study.

4d. Total Window Thermal Losses

Total window thermal loss was the result of non-infiltrative and infiltrative thermal losses through the window as well as thermal losses due to exterior air infiltrating via the rough opening. Sash infiltrative window losses were based on window air leakage characteristics while infiltrative losses due to exterior air were assumed to be the average of the 33 windows discussed previously. Sash and exterior air infiltrative losses were summed for a whole window infiltrative loss. The whole window infiltrative loss was correlated with natural infiltration rates by use of the LBL correlation model. Non-infiltrative thermal losses were based on WINDOW 4.1 modeling. The two estimates were converted to common units and summed together for an “effective thermal loss”.

The validity of an “effective thermal loss” was not tested in this study and is subject to speculation (Klems, 1984). The aforementioned procedure adds the results of two very different methods of calculating heat losses, one based on infiltrative rates resulting from fan pressurization data (the LBL model) and the other the result of a computer model based on well understood thermodynamic principles (WINDOW 4.1). The concept of “effective thermal loss” was chosen for this study in order to provide an all encompassing parameter describing total thermal loss through a window, which enabled a simplification in the subsequent calculation of total heating costs for a window.

4e. Thermography

In February 1996, thermographs were taken of windows at two sites in Hanover, New Hampshire. Images of three windows were taken at Robinson Hall of Dartmouth College. Two of these windows were large, double-hung, pulley-type windows with conventional triple track aluminum storm windows attached. The third window was a Bi-Glass Systems retrofit with vinyl jamb liners, double-pane insulating glass, and silicone bulb weatherstripping at the meeting rail, head, and sill junctions.

The second Hanover site was 4 Occom Ridge, where double-hung, pulley-type windows were fitted with conventional triple track aluminum storm windows, as well as being caulked with rope caulking. One set of windows in the den was also fitted with an interior plexiglass storm window, attached by magnetic stripping.

These sets of thermographs were not used in a quantitative manner but were rather used as a means for visual comparisons between window upgrades.

4f. Energy Savings Due to Window Upgrades

Savings in energy costs for a building were based directly on those savings attributable to energy reduction through window upgrades. This was a direct result of the apparent additive nature of the relationship between thermal losses due to windows and the remainder of whole house thermal losses.

The following steps summarize the process used to calculate annual energy costs and savings due to a window upgrade, as compared to annual costs for typical windows:

1. convert typical sash leakage fan pressurization data (Q_s) as scfm/lfc to effective leakage area (ELA_s/lfc);
2. convert the volume of exterior air (Q_{ext}) as scfm/lfc to ELA_{ext}/lfc, based on a field derived percentage of average extraneous air leakage (Q_e);
3. add ELA_s/lfc to ELA_{ext}/lfc for a window ELA per linear foot crack due to infiltration (ELA_{tot}/lfc);
4. multiply ELA_{tot}/lfc by 19 lfc for a typical 36 x 60 inch double-hung window to determine the whole window ELA (ELA_{tot});
5. use ELA_{tot} in the LBL correlation model to predict the average heating season infiltration rate for the window (Q_{nat} - natural air infiltration rate);
6. multiply the average heating season infiltration rate (Q_{nat}) by the heat capacity of air (C_p) to determine total thermal loss rate through the window due to infiltration (L_{inf}):

$$L_{inf} = Q_{nat} * C_{p_{air}}$$

$$L_{inf} = Q_{nat} * \frac{0.018\,Btu}{ft^3 * {}^\circ F} * \frac{60\,min}{1\,hr}$$

7. calculate non-infiltrative thermal loss rate (L_{non}) due to transmission (U-value) using WINDOW 4.1;
8. multiply the U-value (L_{non}) by 15 ft^2 for a typical 36 x 60 inch double-hung window to determine the total window non-infiltrative thermal loss rate (L_u);
9. add the infiltrative (L_{inf}) and non-infiltrative (L_u) thermal loss rates to determine the "effective thermal loss" of the typical window (L_{eff});
10. determine the annual window thermal loss (L_{yr}) in millions of Btu's (MMBtu) by multiplying the "effective thermal loss" (L_{eff}) by the average Vermont degree-day units by 24 hours per day:

$$L_{yr} = L_{eff} * 7744 \ degree\text{-}days * \frac{24\,hr}{day} * 10^{-6}$$

11. calculate the annual cost per window (C_{win}; example based on number 2 fuel oil):

$$C_{win} = \frac{(fuel\ cost\ per\ gal) * (annual\ heat\ required) * 10^{6}}{(fuel\ heat\ capacity\ per\ gal) * (furnace\ efficiency)}$$

$$C_{win} = \frac{\$0.90/gal * L_{yr} * 10^{6}}{(138{,}600\,Btu/gal) * eff}$$

12. repeat steps 1-11 for a given window upgrade; and
13. determine the annual savings per upgrade type (S_{win}) by subtracting step 12 from step 11.

5. RESULTS

One hundred fifty-one windows at 19 different sites were field tested for this study. Sixty-four windows were tested in their original condition with storms both open and closed when operable. The remaining 87 windows underwent some form of upgrade. Six sites had a total of 29 windows tested both prior to and post renovative work. Two other windows underwent detailed testing in the laboratory.

5a. Appropriateness of Flow Model

The correlation of induced air leakage to natural infiltration rates was dependent on extrapolation of field data from the range of test pressures (0.03 - 0.30 in. H_20) down to 0.016 in. H_2O. Extrapolation was based on the standard mathematical flow model:

$$Q = c * \Delta P^X$$

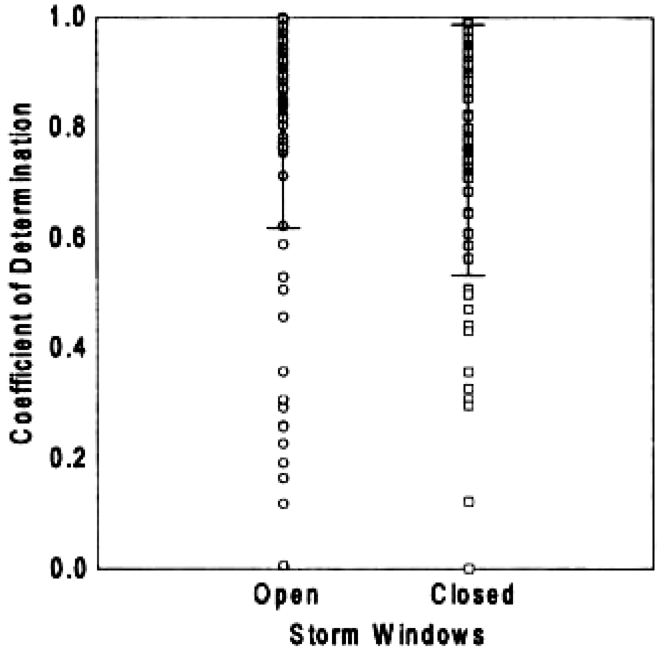
where air leakage is a function of the pressure differential. The degree to which the model accurately described the field data was determined by the value of the coefficient of determination (R^2) for each test, as calculated by linear regression. The coefficient was defined as the proportion of variability in the dependent variable (Q) accounted for by the independent variable (ΔP). Maximum allowable value for R^2 was 1.000, meaning the model was a perfect fit to the field data, resulting in the data falling on a straight line on a log-log graph.

Coefficient of determination values for all windows with storms open and/or closed are shown in Figure 2. The black circles are the mean R^2 values for windows with storms open and closed (R^2 = 0.844 and 0.760, respectively). The lines represent plus or minus one standard deviation from the means and encompass 68% of the data points. The median R^2 value for windows with storms open was 0.921 while the median with storms closed was 0.838. The median represented the middle value of the ranked population, meaning half the population was above the median. In this case, the median values were more robust estimations of the central tendency than the averages, as averages were weighted towards lower R^2 values. It was determined the field data showed a reasonable fit to the flow model, lending confidence to the extrapolated values for air leakage at 0.016 inches of water.

Some variation of R^2 was associated with gusting winds during some testing periods. Depending on direction, these winds had the effect of increasing or decreasing the pressure differential shown in the manometer. Wind induced pressure changes caused unnecessary adjustments of air flow rates to accommodate false pressure readings. Other windows and doors were opened to ameliorate the effects of strong winds.

A larger variation in R^2 values was observed for those windows allowing little induced air

Figure 2: Variability in R^2 values of standard flow model fitted to the field data



leakage. For those windows, the effect of even moderate winds on test accuracy increased as both air flow rates and pressure differentials decreased. Table 3 shows wind speeds equivalent to pressure differentials used in the test, with pressures being expressed in both conventional (Inch-Pound) and metric (SI) formats.

Table 3: Wind speeds equivalent to test pressure differentials

Wind speed (mph)	ΔP (in. H_20)	ΔP (Pa)
25	0.30	75
23	0.25	62.5
20	0.20	50
18	0.15	37.5
14	0.10	25
12	0.07	17.5
10	0.05	
8	0.03	7.5
6	0.016	4

5b. Field Test Results - Original Condition Windows

Sixty-four original condition windows were field tested for air leakage. These data were used to model leakage characteristics of typical, tight, and loose affordable housing windows for comparison with differing window upgrades. The typical double-hung window was assumed to have dimensions of 30 x 60 inches, giving an operable crack perimeter of 19 linear feet and a surface area of 15 square feet.

As previously discussed, a portion of extraneous air leakage made a contribution to the heating load by requiring conditioning. During the latter half of the study, thirty-three windows were monitored for the percentage of exterior air contained in the induced extraneous air leakage during the test period (Appendix E). The average percentage by volume of exterior air entering the test zone within extraneous air was 29% as measured and estimated by temperature differences. This percentage was approximated as 30% for this study. It should be noted again that the validity of the method used to determine the volume of exterior air is open to question. No attempt was made to validate the method in the course of the study.

Field data for each window were converted to sash (Q_s) and extraneous (Q_e) leakage rates, expressed as standard cubic feet per minute per linear foot crack (scfm/lfc). Thirty percent of the extraneous leakage rate was taken to represent exterior air infiltration (Q_{ext}). These results were in turn converted to effective leakage areas per linear foot crack (ELA/lfc) at 0.016 inches of water pressure, the assumed driving force for natural infiltration. After summing the two infiltrative ELA's/lfc, a whole window ELA (ELA_{tot}) was calculated by multiplying the sum by the typical nineteen feet of operable window perimeter.

Table 4 shows assumed air leakage characteristics for typical affordable housing windows based on the field research. Total sash leakage ($ELA_{S\ X\ 19}$) for the typical window was the average of the sash leakage rates of all original condition windows with operable storms in place (35 windows). Both the tight and typical windows were assumed to have storm windows in place, with the tight window having sash leakage characteristics one standard deviation less than the typical window. The loose window was assumed to have no storm in place and was the average of all original condition windows with storms open or missing (47 windows). Based on field measurements of 33 windows, 30% of extraneous air infiltrating a window was assumed to be exterior air and was expressed as a whole window effective leakage area (ELA_{extx19}). Thirty percent of the appropriate averaged extraneous air volume was added to the sash flow ($ELA_{s\ x\ 19}$) of each window to determine a total effective leakage area (ELA_{tot}) for each assumed window.

The column labeled "diameter in Table 4 was included to facilitate visualizing ELA_{tot} It refers to the diameter of the round orifice on which ELA is modeled. As previously stated, ELA is the size of a round orifice passing the same air flow as the cracks associated with a window.

Table 4: Assumed air leakage characteristics for original condition windows

Window Category	$ELA_{s\ x\ 19}$ (in^2)	$ELA_{ext\ x\ 19}$ (in^2)	ELA_{tot} (in^2)	Diameter (in)
Tight Window	0.27	0.59	0.86	1.04
Typical Window	0.89	0.59	1.48	1.37
Loose Window	2.19	0.59	2.78	1.88

The significance of the exterior air contribution to the infiltrative heating load associated with a window may be seen from the above data. Exterior air contributes approximately 20% of the loose window infiltrative load, but rises to 40% and 70% of the total infiltrative heat load for typical and tight windows respectively.

5b i. Air leakage characteristics of windows over time

Air leakage characteristics of three windows at the Central Vermont Community Land Trust (CVCLT) in Montpelier, Vermont, were measured periodically over a time span of eight months, from March until October 1995. The purpose of this long term monitoring was to observe how air leakage responded to environmental factors as the seasons progressed. Wooden windows often become more difficult to operate during the summer season as wood swells in response to an uptake in moisture. The expansion and contraction of the wood affects gap sizes in a window, thereby influencing the rate of infiltration. An understanding of how leakage characteristics changed with long-term weather conditions was desired to determine when field testing was to begin and end, so as to maintain similar test conditions. Potential environmental parameters influencing moisture uptake by wooden windows (and thus potentially affecting air leakage rates) included exterior dry-bulb temperature, relative humidity, dew point temperature, and partial water vapor pressure:

- Exterior dry-bulb temperature - the current ambient air temperature as measured by a thermometer.
- Relative humidity - the ratio of the amount of water vapor in the air to the maximum amount of water vapor the air can hold at the ambient temperature.
- Dew point temperature - the temperature at which the ratio of water vapor pressure to atmospheric pressure is equal to the mole fraction* of water vapor in the air. This is the temperature at which water vapor condenses from the air to form liquid water (dew).
    - Mole fraction - the ratio of the number of moles of a component (water) to the total number of moles of all components in the mixture (air).
- Partial water vapor pressure - that component of the atmospheric pressure exerted solely by the water vapor contained in the air mass.

The relative humidity, dew point temperature, and partial water vapor pressure are all related as they are dependent on the mole fraction of water vapor in air and the dry-bulb temperature (Appendix D).

Water vapor pressure was the likely driving force in the uptake or release of moisture by wooden windows. The wood in windows of historical buildings was assumed to be air dried to the extent it exhibited a response to changing atmospheric moisture conditions by swelling or shrinking. An increased amount of moisture in the air increased atmospheric water vapor pressure, thereby increasing the water vapor pressure differential between air and wood. It was the pressure differential between atmospheric water vapor and wood moisture content that was assumed to be the driving force for changes in dimensions of wooden windows, which in turn affects rates of air leakage.

The assumption concerning air infiltration rates, wooden windows, and increased atmospheric moisture content during the summer season was that air infiltration would decrease as the summer season progressed, as wood swell would decrease the size of any gaps in the windows, essentially reducing the effective leakage area (ELA). Data from the CVCLT windows monitored over time were unclear as to general leakage trends with seasonal progression.

Total window leakage rates (Q_t) were converted to effective leakage areas for comparison overtime. Windows 1A and 1B exhibited a general decline in ELA while the storm window was in place. This trend was not as apparent when data with storm windows open was observed. Window 1 C showed no general trends, either with the storm window open or closed. No strong correlations were found between air leakage rates and running averages of the four parameters tested when using running averages of one to six weeks. Significant correlations likely required a longer monitoring period and more windows for a larger data base. Such an investigation was beyond the scope of this study. Field testing was halted in May 1995 and resumed in October 1995 and was continued through June 1996 when weather permitted.

5b ii. Leakage characteristics of pin- versus pulley-type windows

Original condition windows were separated into pin- and pulley-type windows to determine if pulley-type windows allowed more air leakage. Leakage through the sash (Q_s) was expected to be equivalent while extraneous leakage (Q_e) was expected to differ, with more extraneous leakage in pulley-type windows than pin-type. A separate variance t-test showed no difference in sash leakage rates (Q_s) between the window types at a 95% confidence level. Pulley-type window extraneous air leakage rates (Q_e) were significantly greater than those for pin-type windows at a 99% confidence level Extraneous air values, expressed as whole window extraneous leakage areas ($ELA_{e \times 19}$) are shown in Table 5.

Separate variance t-tests for windows with storms closed showed similar results as above at confidence levels of 95%. Data for the original condition windows with storms closed were not listed as only interior storm windows decreased the volume of extraneous air entering the test zone. No original condition windows were fitted with interior storms.

Table 5: $ELA_{e \times 19}$ values for original condition pin- versus pulley-type windows with storms open

Window type	n	$ELA_{e \times 19}$ (in^2)	D (in)
Pin	23	1.39	1.33
Pulley	32	2.37	*1.74*

The observed increased air flow around pulley-type windows indicates the importance of window weight cavities to air infiltration and the efficient use of energy during the heating season.

5b iii. Sash leakage reduction due to existing storm windows

The effect of existing storm windows on reducing sash leakage through windows was investigated using data from the original condition windows. Of the 64 original condition windows tested, 24 had data for storm windows in both the open and closed positions. Many windows with attached storm tracks had missing or broken panes. Others were inaccessible due to both sash being painted shut on the interior side

Sash air leakage characteristics for those windows with operable storms were calculated with storm windows in both the open and closed positions. Results were expressed as whole window effective sash leakage area (ELASX 19) and compared using a paired t-test. At a confidence level of 99.9%, windows with existing storms in the open position allowed significantly more sash leakage than did those same windows when storms were in the closed position. Results are found in Table 6, as well as the percentage reduction in sash leakage caused by storm windows in the closed position.

Table 6: comparison of 24 original condition windows with existing storms open and closed

Storm Window Position	$ELA_{s \times 19}$ (in^2)	D (in)	Sash Leakage Reduction
Open	1.86	1.54	---
Closed	1.01	1.13	46%

Reduction in air flow was expected through the sash but was not expected in terms of extraneous air leakage. All existing storm windows encountered were exterior storm windows and thus had no effect on air leaking through the rough opening. To test this assumption, extraneous leakage data were compared using a paired t-test. No significant difference in extraneous air leakage was found between windows with storms in the open and closed positions at a confidence level of 99%.

5b iv. Air leakage characteristics of single- versus double-hung windows

The manner of a window's operation was investigated to determine its bearing on sash leakage characteristics. Thirteen of the original condition windows were single-hung, with the other 51 being double-hung windows. Of the 13 single-hung windows, one (6B) was discounted as it had a wooden storm window caulked into place and could not be removed. That prevented characterizing the window's sash leakage with the storm window off, the condition required to compare single- versus double-hung windows. Sash leakage characteristics with storm windows open were determined for 35 of the 51 original double-hung windows, the remainder having inaccessible storm windows in the closed position.

The upper sash of three single-hung windows (6A, 6C, and 6D) were held in place by wooden stops, but were also caulked to the jamb. These three windows were considered to be true single-hung windows in terms of air leakage, with scfm/lfc based on an operable perimeter of *H + 2xW.* These three windows with caulked upper sash were separated from the other single-hung windows as their leakage characteristics were determined using a different operable perimeter.

Nine of the remaining 12 single-hung window's had the upper sash held in place by a wooden stop or nail. The upper sash fitted loosely in its frame in these instances, allowing air leakage through the sash/jamb junction. Single-hung windows such as these were considered to be double-hung in terms of calculating air leakage as scfm/lfc since air leakage sites in these windows were identical to those for a double-hung window. Operable window perimeter was calculated as *2xH + 3xW* for these windows.

A separate variable t-test was used to compare sash leakage rates of the 35 double-hung windows versus the nine single-hung in terms of whole window effective leakage area (ELAsx19). The 35 double-hung windows allowed significantly less sash leakage than the nine single-hung at a confidence level of 99%. Lower sash leakage for double-hung windows was an unexpected result, considering single-hung windows were characterized not by operable crack perimeter, but by available leakage perimeter and were thus equivalent to double-hung windows. Average leakage characteristics for the original condition windows, expressed as ELASX19, are listed in Table 7

Table 7: Single- versus double-hung window sash leakage characteristics

Window Type	n	$ELA_{s \times 19}$ (in^2)	D (in)
Single-hung	9	3.12	1.99
Double-hung	35	2.00	1 .60

When sash leakage rates of the three "true" single-hung windows were compared to the other nine single-hung, no significant difference in sash leakages rates was found at a confidence level of 95%. Although not investigated further, a larger sample population of single-hung windows would need to be tested to determine the validity of these results.

5b v. Correlation of descriptive physical parameters with air leakage rates

An early goal of the study was to investigate the possibility of visually inspecting a window and estimating if sash leakage rates were low or high The physical condition of each original condition window field tested was categorized using a check list of 12 subjective parameters describing the general sash, sash/jamb fit, and the glazing (Appendix C).

Descriptive physical parameters were reduced to overall sash condition (glazing and putty for both sash), sash/frame fit (tightness of sash in jamb and squareness), a combined sash/frame and meeting rail fit, and the total gap width on the lower sash side. The meeting rail fit and squareness of the sash in the frame were also investigated as independent parameters. Correlations of all parameters with sash whole window effective leakage area (ELAS 19) and extrapolated sash leakage rates at 0.30 inches of water pressure were investigated for those original condition windows with storms open or missing. Extrapolated values rather than actual sash leakage rates were used as a means of comparison as only ten of 47 windows thus described were able to achieve a test pressure differential of 0.30 inches of water.

There was no significant correlation between overall sash condition, sash/frame fit, sash/jamb squareness, or total gap width with either ELAS 19 or extrapolated sash leakage rates ($R \leq 0.26$ for all four). The $ELA_{s\ x\ 19}$ showed a weak inverse correlation ($R = -0.43$, $p = 0.002$) with the combined parameter sash/frame/meeting rail fit, with ELA_{sx19} increasing as the combined parameter decreased in value. Both $ELA_{s\ x\ 19}$ and extrapolated sash leakage rates had a weak inverse correlation with the meeting rail, with the correlation between $ELA_{s\ x\ 19}$ stronger than the extrapolated sash leakage rate correlation ($R = -0.69$, $p < 0.001$ and $R = -0.41$, $p = 0.004$ respectively). Visual inspection of a window therefore gave little indication as to its leakiness.

5b vi. Original condition window summation

It was found that exterior air can have a significant role in adding to the heat load of any window, whether it be tight or loose. Pulley-type windows were found to be significantly leakier than pin-type windows when including extraneous air leakage, largely due to the presence of a window weight cavity. The window weight cavity provided greater potential for exterior air to infiltrate the window from the rough opening. The window weight cavity provided greater potential for exterior air to infiltrate the window from the rough opening. Single-hung windows were found to have significantly more sash leakage than double-hung regardless of the method used to calculate operable crack perimeter. No significant correlations were found between leakage rates and four environmental parameters nor between leakage rates and visual window appearance

5c. Field Test Results - Window Upgrades

The second round of field testing involved pressurization tests of a variety of window upgrades on eighty-seven windows. Upgrades ranged from retaining the original sash to window inserts utilizing the existing jamb. Table 8 summarizes the number of windows (n) tested for each general upgrade category, with some windows falling into two categories.

Table 8: Number of windows tested by general window upgrade category

General Window Upgrade Category	n
Retain original sash	62
Replacement sash with vinyl jamb liners	11
Replacement window inserts	12
Whole window replacements	2
Replacement storm windows	17
Double- versus single-glazing replacements	19

5c 1 Upgrades retaining the original sash

Sixty-two renovated windows retained the original sash with 59 of those windows at nine sites also retaining the original glazing by employing a variety of weatherstripping, vinyl jamb liners, and/or storm window upgrade options. Three other windows retained the original sash by undergoing the Bi-Glass System upgrade which replaced single-glazing with double-pane insulating glass. Thirteen windows retaining the original sash had no improvement other than the addition of replacement storm windows. Those 13 windows are discussed in the section concerning storm window replacement.

Upgrade options tested in the field are summarized in Table 9, along with the number of windows tested for each upgrade type Average sash air leakage characteristics for each upgrade type are also shown, expressed as sash whole window effective leakage areas ($ELA_{s \times 19}$) Data for windows with any storms in place are not included, as the effect of storm windows would mask reductions due to sash upgrades. Also listed along with sash leakage characteristics are 30% of the average extraneous air leakage values for each upgrade type ($ELA_{ext \times l9}$), accounting for exterior air contributions to whole window leakage. These two values are summed for a whole window effective leakage area (ELA_{tot}) for each upgrade type.

The six windows with Caldwell coiled spring balances (site 16) show no data in Table 9 as the average maximum pressure attained during total window testing (Q_t) averaged 0.025 inches of water. These windows were extremely leaky, with nothing having been done to prevent air from passing through the old window weight cavities or the large gaps at the

Table 9: Average leakage characteristics for upgrade types retaining original sash

Site ID	Upgrade Description	n	Q_s Ext. (scfm/lfc)	$ELA_{s\ x19}$ (in^2)	$ELA_{ext\ x\ 19}$ (in^2)	ELA_{tot} (in^2)	D (in)
12	Vinyl jamb liners; no weather stripping	7	1.80	2.49	0.56	3.05	1.97
13	Vinyl jamb liners; silicone bulb weatherstripping at sill and head junctions	8	1.40	2.23	0.56	2.79	1.88
7	Vinyl jamb liners; silicone bulb weatherstripping at sill, head, and meeting rail junctions	19	0.78	0.87	0.26	1.13	1.20
2	Bi-Glass System with vinyl jamb liners; silicone bulb weatherstripping at sill, head, and meeting rail junctions; double-pane insulating glass; new latch at meeting rail	3	0.48	0.71	0.33	1.04	1.15
16	Caldwell coiled spring balances with silicone bulb weatherstripping at sill and head junctions; some weatherstripped wooden storm windows	6	***	***	1.32	***	***
17	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	3	0 18	0.48	0.61	1.09	1.18
19	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	2	0.49	0.54	0.17	0.71	0.95
10	Sash weatherstripped with Polyflex T-slot between sash face and parting bead; Polyflex at sill, head, and meeting rail junctions	1	0.10	0.29	0.42	0.71	0.95

meeting rails. This is reflected in the high value for exterior air effective leakage area (1.32 in^2), which is based on only 30% of the extraneous air measured during the field tests.

The lowest sash whole window effective leakage area (ELA_5 x 19) was the window with Polyflex weatherstripping. That value should not be considered typical of the upgrade type as only one example was tested. That specific window required major sash repair prior to weatherstripping, with the entire renovation process requiring twelve man-hours. It was not determined how much sash leakage reduction was a result of sash repair as opposed to weatherstripping.

Both sites 10 and 19 showed equivalent values for whole window effective leakage area

(ELA_{tot} = 0.71 in^2) while having significantly different sash leakage rates (0.29 and 0.54 in^2, respectively). The discrepancy arose from the whole window exterior air leakage area ($ELA_{ext\ x\ I9}$). Site 10 had a significantly larger $ELA_{ext\ x\ I9}$ than site 19 (0.42 and 0.17 in^2, respectively) which was assumed to be more an artifact of building construction rather than window renovation. This further illustrated the significant contribution exterior air can have when determining the heat load of a window.

Both the zinc rib-type and bronze V-strip weatherstripping upgrades show relatively low values for $ELA_{s\ x\ 19}$ (0.48 and 0.54 in^2, respectively). The Bi-Glass System upgrade has an $ELA_{s\ x\ 19}$ substantially greater than either the rib-type or V-strip weatherstripping (approximately 50% and 30%, respectively). It should be kept in mind that the number of samples for these three upgrades is very small and not statistically valid. Comparisons of results should therefore be viewed with caution.

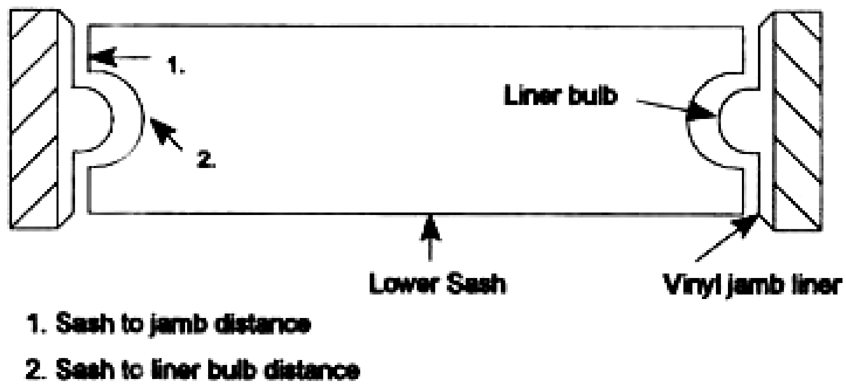
Field sash leakage rates expressed as $ELA_{s\ x\ 19}$ for the three Bi-Glass System upgraded windows are slightly larger than results from the one laboratory window having undergone the Bi-Glass System upgrade (0.71 in^2 versus 0.65 in^2). Due to the nature of the lab set-up, no comparisons could be made for $ELA_{ext\ x\ I9}$ or ELA_{tot} It should be noted that the three field windows were pin-type windows while the lab window was a pulley-type. As noted previously, pulley-type windows had significantly more sash leakage than pin-type but once again, caution should be taken when interpreting these results due to extremely low sample populations.

Windows at sites 7, 12, and 13 used the same brand of vinyl jamb liner, with upgrade differences being found in the location or absence of silicone bulb weatherstripping. Site 12 had no weatherstripping, with the exception of one sill junction. Site 13 had the same size and type windows as site 12, but had weatherstripping inserted into sill and head junctions. No significant difference between the two sites was found for $ELA_{s\ x\ 19}$ at a 95% confidence level.

Site 7 had two window sizes, both larger than the windows at either site 12 or 13. These windows had silicone bulb weatherstripping inserted into the sill, head, and meeting rail junctions. There was a significant difference in $ELA_{s\ x\ 19}$ between site 7 and site 13 at a 99.9% confidence level, with the only difference between the two being weatherstripping at the meeting rail junction. The meeting rail gap had a weak correlation with sash leakage as discussed previously, so addition of weatherstripping at the meeting rail junction likely accounted for a portion of the sash leakage reduction. To further investigate the difference, the jamb liner bulb/sash distance and jamb/sash distance were measured to see if a correlation existed between sash liner fit and sash leakage. Areas of measurement are shown in Figure 3. No significant correlations (R c 0.28, p = 0.05) were found between sash/jamb liner measurements and $ELA_{s\ x\ 19}$ for any of the three sites.

Separate variance t-tests showed site 12 windows to have significantly larger jamb liner/sash gaps than either site 13 or 7 at a 97% confidence level while having statistically the same $ELA_{s\ x\ 19}$ as site 13. Routing of the sash to accommodate vinyl jamb liners was

Figure 3: Schematic of lower sash and vinyl jamb liner junction



done by the same work crew at sites 12 and 13. A different work crew performed the work at site 7. No significant difference in jamb liner/sash gaps was found between sites 7 and 13 at a 98% confidence level while there was a significant difference in $ELA_{s \times 19}$ between the sites. Based on the limited data, it is inconclusive as to whether differing work crews had a significant effect on installation quality. In an earlier study, few significant differences in leakage rates were observed when differing contractors installed the same type windows in new residential housing in Minnesota (Weidt, 1992). It remained unresolved as to why site 7 window upgrades had better sash leakage characteristics than sites 12 and 13.

New windows are characterized by sash leakage rates per linear foot crack and must meet the industry standard of 0.37 scfm/lfc at 0.30 inches of water pressure in order to be certified. Table 9 also lists average extrapolated sash leakage rates (Q_s) at 0.30 inches of water for each upgrade type. Actual sash leakage averages could not be used for comparative purposes as only 21 of 52 windows were of sufficient tightness to attain 0.30 inches of water pressure.

Averaged sash leakage rates of the tightest original sash fitted with vinyl jamb liners and weatherstripping (0.78 scfm/lfc at 0.30 in. H_2O, site 7) showed significantly more sash leakage than the certifiable industry standard window (0.37 scfm/lfc at 0.30 in. H_2O) at a 99.9% confidence level. While other original sash upgrade options such as the Bi-glass System and weatherstripping options appear to have large sash flow reductions, caution must be taken in drawing conclusions concerning those upgrades as no upgrade option had more than three windows tested, sample populations with little statistical significance.

5c ii. Replacement sash upgrades

Two makes of replacement sash utilizing vinyl jamb liners were encountered during field testing, accounting for eleven windows. Both makes were in-kind replacement units with single-glazing and utilized the existing jamb. Table 10 presents leakage characteristics of these windows based on extrapolated values. Three of the eleven windows did not allow attainment of the maximum pressure (0.30 in. H_2O), although two (12B, 12D) allowed pressurization at 0.25 inches of water pressure. The third window (131) was installed in an

Table 10: Leakage characteristics for 11 replacement sash

Q_s Reg. Avg (scfm/lfc)	$ELA_{s\ x\ 19}$ (in^2)	$ELA_{ext\ x\ 19}$ (in^2)	ELA_{tot} (in^2)	D (in)
0.29	0.45	0.30	0.75	0.98

out-of-square frame, with 5 mm gaps at opposing upper and lower corners, attaining a maximum pressure of 0.07 inches of water.

The average extrapolated leakage rate for the in-kind replacement sash (0.29 scfm/lfc) is significantly less than the 0.37 scfm/lfc certifiable standard set by the window industry (confidence level of 99.9%). The in-kind replacement sash met the certifiable standard for air leakage in new windows and were considered tight windows.

Two other sets of replacement sash (18A, 18B) were placed in visually out-of-square frames resulting in reported high levels of discomfort during the winter. These two windows underwent extensive sealing to reduce sash and extraneous air leakage after one heating season. It is apparent from leakage characteristics of windows 13l, 18A, and I8B that squareness of frame was an important issue when using replacement sash.

5c iii. Window insert upgrades

Fourteen replacement window inserts at four sites, representing two manufacturers, were field tested during the study. All but one of these windows (16G) attained the maximum pressure. The extraneous air leakage test (Q_e) for window I 6G revealed a large volume of air leaking through the rough opening (maximum Q_e pressure **-** 0.07 in. H_2O), an atypical result for other window inserts tested. Table 11 summarizes window insert sash leakage data, both including and excluding window 16G.

Table 11: Sash leakage characteristics for replacement window inserts

	Q_s Actual Avq (scfm/lfc)	Q_s Ext. Avg (scfm/lfc)	$ELA_{s\ x\ 19}$ (in^2)	$ELA_{ext\ x\ 19}$ (in^2)	ELA_{tot} (in^2)	D (in)
16G excluded	0.14	0.13	0.12	0.09	0.21	0.52
16G included	---	0.17	0.13	0.16	0.29	0.61

Window 16G illustrated the importance of sealing the rough opening to reduce exterior air infiltration. When data from window 16G was included, the average $ELA_{ext\ x\ 19}$ increased by approximately 75%. Window 16G also showed window inserts may not necessarily reduce exterior air infiltration significantly.

Replacement window inserts were expected to reduce extraneous air flow as they consisted of both sash and an integral frame. Table 12 compares the average volume of exterior air for window inserts to other upgrade categories and also shows extrapolated sash leakage rates at 0.30 inches of water pressure (Q_5). Replacement window insert 16G was excluded from the data as it was considered to be atypical in terms of extraneous air leakage.

Table 12: comparison of exterior air volumes by upgrade type

Upgrade category	Site Number(s)	n	Q_s Ext. (scfm/lfc)	$ELA_{ext\ x\ 19}$ (in^2)	D (in)
Window insert	6,7,11	13	0.13	0.09	0.34
Replacement sash	3, 12, 13, 18	11	0.29	0.30	0.62
Bi-Glass System	2	3	0.48	0.33	0.65
Original sash with vinyl jamb liners	7,12,13	34	1.14	0.39	0.70

A significant reduction in ELAex19 was achieved by the use of window inserts at a 99.9% confidence level. This was likely a result of the insert's integral frame sealing the existing jamb.

5c iv. Storm window upgrades

Four different configurations of storm window upgrades were field tested, encompassing both new storm windows and upgrades of existing storm windows. General configurations of storm windows were aluminum triple track, aluminum fixed sash with removable lower pane, fixed wooden sash, fixed interior pane,and two aluminum triple track storms installed as interior storm windows. The number and type of each storm window are listed in Table 13 as well as the percentage reduction in sash air leakage when the storm window was closed.

An overall improvement could not be determined for site 16 windows due to their extremely leaky nature.

Sash leakage reduction varied between the types of storm windows with interior storms providing the largest percentage reduction. This was clearly illustrated at site 14 where six windows were tested, four with aluminum triple track storm windows mounted on the exterior and two with identical storm windows mounted on the interior. The four exterior storm windows reduced sash leakage by 75% while the two interior storms reduced sash leakage by 96%.

A wide range of variability was observed in sash leakage reduction for windows fitted with new aluminum triple track windows. The variability was dependent on site and was likely a result of installment procedures. Aluminum frames at site 14 were caulked to the exterior

Table 13: Storm window upgrades by type

	Upgrade Description	Site ID	n	Q_s Open (scfm/lfc)	Q_s Closed (scfm/lfc)	% Q_s Red.
New	Aluminum triple track, replacement	10	1	1.80	0.93	50%
		14	4	1.16	0.27	75%
		17	3	0.18	0.11	35%
	Aluminum fixed sash, removable lower sash	10	1	1.10	0.48	55%
	Wooden sash, replacement	7	1	2.00	1.32	35%
	Interior mount, aluminum triple track, replacement	14	2	1.11	0.04	96%
	Interior storm window, spring loaded metal frame	10	1	1.10	0.05	95%
	Interior storm window, plexiglass with magnetic stripping	15	4	0.90	0.01	98%
Original	Aluminum triple track, existing frame caulked	19	2	0.49	0.35	30%
	Wooden sash, felt weatherstripping	16	4	***	***	***

*** No data available

trim and were affixed to leaky prime windows (average extrapolated Q_s = 1.14 scfm/lfc). This was reduced to an average extrapolated sash leakage rate of 0.19 scfm/lfc for all six windows when the storms were closed. Site 17 frames had also been caulked in place but were three years old. Compared to site 14, the prime windows at site 17 were much tighter (average extrapolated Q_s = 0.18 scfm/lfc, reduced to 0.11 scfm/lfc with storms closed), an effect that decreases the importance of a reduction due to an effective storm window. Sample populations for all storm window types were too small to allow for valid statistical studies, but can be seen to reduce sash leakage rates.

As well as reducing sash leakage (Q_s) interior storm windows provided the additional benefit of reducing extraneous air leakage (Q_e) by their installation within the interior window jamb, thus blocking air leakage from the rough opening. A drawback to interior storm windows as reported in the literature was the potential to cause moisture related problems from accumulated condensation. Two sites (10 and 15) had fixed panel interior storm windows, while a third location (site 14) had two aluminum triple track storm windows installed on the interior window. Interior installation in this building was done to maintain the historic appearance of its front facade. Table 14 summarizes the reduction in extraneous leakage achieved by each interior storm window configuration. While reductions in extraneous air leakage are large, the small sample numbers should be noted.

Table 14: Percent reduction in extraneous leakage by interior storm window configuration

Interior Storm Window	Site ID	n	Q_s Open (scfm/lfc)	Q_s Closed (scfm/lfc)	Percent Q_e Reduction
Glass with metal frame	10	1	0.77	0.33	60%
Plexiglass with magnetic stripping	15	4	4.22	0.34	90%
Aluminum triple track	14	2	1.13	0.46	60%

5c v. Double- versus single-glazing upgrades

Nineteen of the 87 window upgrades were fitted with double-pane insulating glass. Sixteen double-glazing upgrades were either replacement sash or window inserts, with the remaining three windows being original sash using the Bi-Glass System upgrade. Infiltrative differences were not expected between double- and single-glazed sash as glazing did not affect leakage in upgraded windows. Thermal transmission differences due to a second glazing layer were expected however, and were modeled using WINDOW 4.1. Table 15 lists non-infiltrative loss rates as calculated by WINDOW 4.1 based on a double-hung window with dimensions of 36 x 60 inches. Also included are non-infiltrative thermal loss rates for assumed tight, typical, and loose windows.

The U-values for double-glazed windows and single-glazed windows with storms are relatively similar (0.49 versus 0.51, respectively). Although not encountered during field testing, low-e glazing options were modeled using WINDOW 4.1 and are included in Table 15. It can also be seen that low-e glazing significantly reduces thermal non-infiltrative loss rates regardless of glazing layers.

Any possible effects of wind-driven infiltration moving into the storm window/sash space were not taken into account, that interaction being beyond the scope of the study. Such effects could change non-infiltrative thermal heat loss rates through a window.

Table 15: Non-infiltrative thermal loss rates for assumed windows and glazing replacements

Site ID	Window Description	n	U-value (Btu/hr-ft^2-°F)	R-value (hr-ft^2-°F/Btu)
---	Typical and tight: single-glazed, storm windows	---	0.51	1.96
---	Loose: single glazed, no storm window	---	0.92	1.09
2, 7, 11, 16, 18	Double-glazed insulating wood sash, 1 over 1	13	0.49	2.04
6	Double-glazed insulating vinyl sash! frame, 1 over 1	6	0.47	2.13
***	Single-glazed prime sash with low-e storm window	---	0.43	2.33
***	Low-e, single-glazed sash with standard storm window	---	0.37	2.70
***	Low-e, double-glazed insulating sash	---	0.35	2.86

***Not encountered in the field – results from modeling

5c vi. Window upgrades summation

The importance of exterior air contributing to the overall heat load of a window was seen throughout all upgrades. Exterior air percentages were often as great or greater than sash leakage percentages. Window inserts generally reduced exterior air leakage significantly by virtue of an integral frame. Replacement sash were shown to be effective in reducing sash leakage when placed in a square frame.

Second glazing layers reduced non-infiltrative losses significantly, whether the second layer was a storm window or double-pane insulating glass. Low-e glass was shown to reduce non-infiltrative loss rates even further. Replacement storm windows provided the benefit of a second glazing layer while reducing sash leakage. Interior storm windows reduced sash leakage even further while also reducing exterior air leakage.

Original sash utilizing vinyl jamb liners stilt allowed significant sash leakage, although no correlation was found between sash fit and leakage rates. It was inconclusive as to the effect installation practices had on these leakage rates.

5d. Laboratory Test Window Data

Two double-hung, pulley-type windows were purchased from a salvage warehouse to be used for laboratory testing. The purposes of testing windows in a laboratory were as follows:

1. to test the repeatability of the test procedure and equipment under controlled conditions;
2. to investigate the location of air leakage sites in detail;
3. to test improvements due to routine maintenance and various upgrades; and
4. to compare laboratory results of an upgrade to its field results.

These two windows appeared to be in better condition than many of the original condition windows encountered during field testing. Both lab windows had meeting rails that fit well with operable sash locks. Both windows also had a good sash to jamb fit, sitting squarely in their frames.

Walls were constructed of 2 x 6 lumber with quarter inch plywood facing to support the test windows. No effort was made to mimic older building styles as the intent was to prevent extraneous air leakage via the rough opening from entering the test zone, eliminating a variable (ie exterior air) that is difficult to quantify. Rough openings were sealed against air leakage from other wall areas with plastic and duct tape prior to installation of the windows to ensure measured air came solely through the window (ie, sash leakage, Q_s), removing the need for the exterior plastic sheet as required by ASTM E783-93. The effectiveness of the plastic was tested after window installation by running the fan pressurization test as performed under field conditions. At 0.30 inches of water (the maximum test pressure), a sash air leakage rate below 1.2 cfm was observed for the entire window. This observed leakage rate was lower than the limits of resolution of the pressurization unit flow meter, meaning any leakage was below the measurement capabilities of the test unit. It was therefore assumed the rough opening had been effectively sealed.

5d i. Identification of leakage locations in lab window A

Lab window A was not immediately upgraded, being first tested in its original condition with missing putty, loose glass, and little paint. This was to provide a comparison to routine maintenance. Routine maintenance was considered to be applying new putty, repointing if necessary, and painting of the woodwork. The edge of the exterior trim was also caulked, a step that would reduce extraneous air leakage in the field. These steps provided some idea of the efficacy of simple maintenance in reducing air infiltration as well as a baseline for comparison to more costly rehabilitation options.

Lab tests for window A were comprised of isolating and testing window leakage areas for respective leakage rates to gain a sense of where the majority of leakage occurred. Leakage sites were chosen on the assumption they would likely be addressed during window renovations. The exception is site F, the inside edges of the exterior trim. This site, along with air from the outside edges of the exterior trim, was chosen to investigate the amount of air entering the test zone by way of the window weight Cavity. Each leakage area was tested six times for statistical validation and was also used to check the reproducibility of the portable air test unit. Individual leakage sites of the window were identified as follows:

A - the window as a whole unit;
B - the meeting rail;
C - the upper sash with the meeting rail sealed;
D - the lower sash with the meeting rail sealed;
E - the junction between the sill and the lower sash;
F - the inside edges of the exterior trim; and
G - the outside edges of the exterior trim.

Reproducibility in terms of the test unit and day-to-day testing (reproducibility over time) were questions specifically addressed during testing of the window as a whole unit (leakage site A). Three sets of three tests were run over the course of nine days to determine the reliability of test results. The air test unit was found to be reliable in terms of reproducibility, with the nine sets of data points falling on top of each other (Figure 4).

These same sets of data also demonstrate the reproducibility of the test over a period of nine days, resulting in a high degree of confidence in the test procedure and the fan

Figure 4: Reproducibility of lab pressurization test results and test device over time

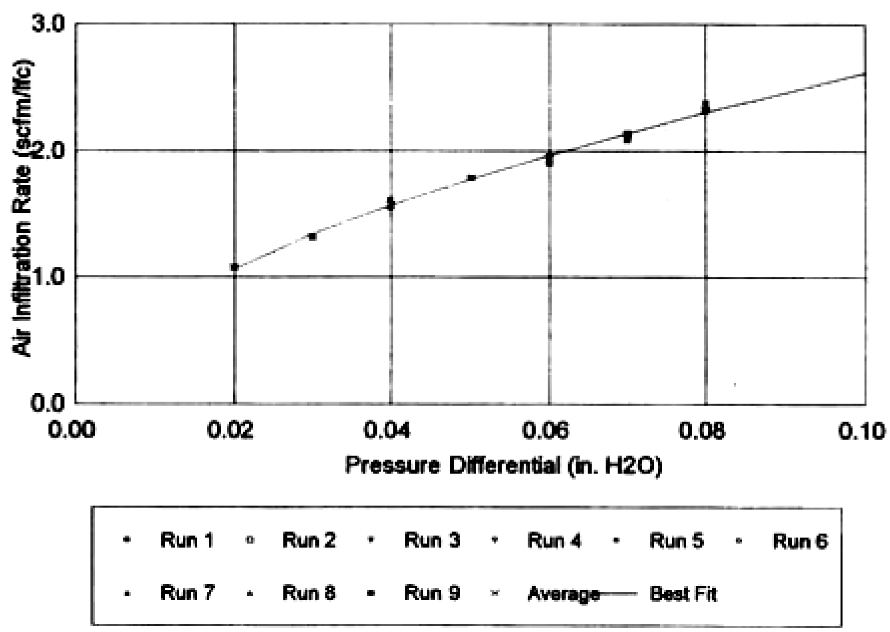
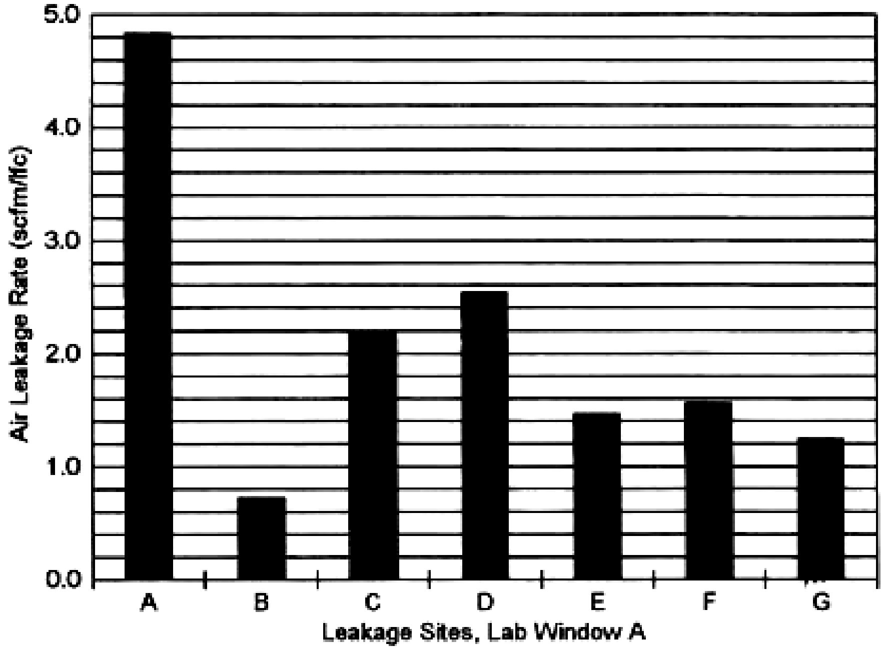


Figure 5: Lab window A leakage rates by site at 0.30 in. H_2O for original condition window



A - Leakage rate through the total window (extrapolated value)
B - Leakage rate through the meeting rail
C - Leakage rate through the upper sash with the meeting rail sealed
D - Leakage rate through the lower sash with the meeting rail sealed (extrapolated value)
E - Leakage rate through the sill junction
F - Leakage rate through the inside edges of the exterior trim
G - Leakage rate through the outside edges of the exterior trim

pressurization unit.

Each individual leakage site investigated using lab window A exceeded the certifiable industry sash leakage standard for whole windows of 0.37 scfm/lfc at 0.30 inches of water pressure for new window units. Figure 5 shows sash leakage rates of the various sites tested on lab window A. Both the window (A) and lower sash (D) failed to attain the specified test pressure of 0.30 inches of water and values shown are extrapolations, based on regression coefficients. Lab window A was considered to be an extremely leaky window as 0.30 inches of water pressure could not be attained for some individual sections.

Examination of Figure 5 shows air leakage rates did not appear additive, as the total window leakage rate should have been equivalent to the summed leakage rates of other leakage sites at equivalent pressures, excluding the sill junction (E). The sill junction was excluded from the summation as it was incorporated in the lower sash reading. Total window leakage rate was just under 5 scfm/lfc while the sum of the individual sites, physically identical to total window leakage sites, was well over 8 scfm/lfc. While the underlying cause of the discrepancy in summing leakage rates was not investigated, it is possible that different masking combinations for differing leakage sites affected the mobility of window components. Changing mobility would allow a component to remain stationary under one masking combination while moving freely under another, affecting the air leakage rates.

It can be seen that for this one window, both the upper and lower sash each accounted for approximately half the total window leakage when tested individually, constituting major leakage sites. The above data are based on one window and should therefore not be considered representative of typical windows.

5d ii. Improvements due to routine maintenance

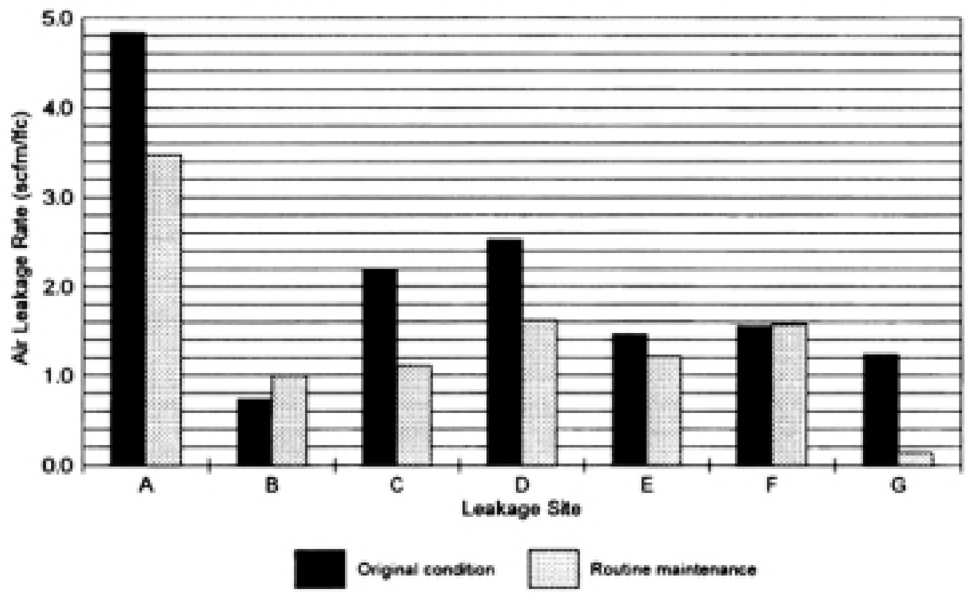
The same leakage sites were retested after lab window A underwent what had been deemed routine maintenance. Routine maintenance included new putty around the glazing of both sash and caulking of the exterior trim/wall junction. New putty was expected to decrease sash leakage (Q_s **)** while caulking was expected to decrease what would be extraneous air leakage (Q_e) in the field.

Expected reductions in air leakage were observed, as illustrated in Figure 6. Also included are the data from Figure 5 for comparative purposes. Reductions in sash leakage rates at 0.30 inches of water pressure were significant at a confidence level of 98%, but the lab window would still be classified as a loose window in the field due to a whole window leakage rate over 3.4 scfm/lfc.

Six of the seven individual leakage sites investigated were still above the certifiable industry standard for whole window sash leakage. The one exception was site G, which allowed air leakage between the wall and outside edges of the exterior trim. This site was the area receiving caulk, a procedure that would reduce exterior air infiltrating around a window in a building. Sash leakage rates (sites C, D) were reduced an average of 65% after routine maintenance, while leakage around the exterior trim/wall junction was reduced by 90%. An overall leakage reduction of 35% was observed for the window as a whole. Simple window maintenance can significantly reduce air leakage for loose windows, but still allow significant leakage. Leakage reduction would not be as significant for tight windows.

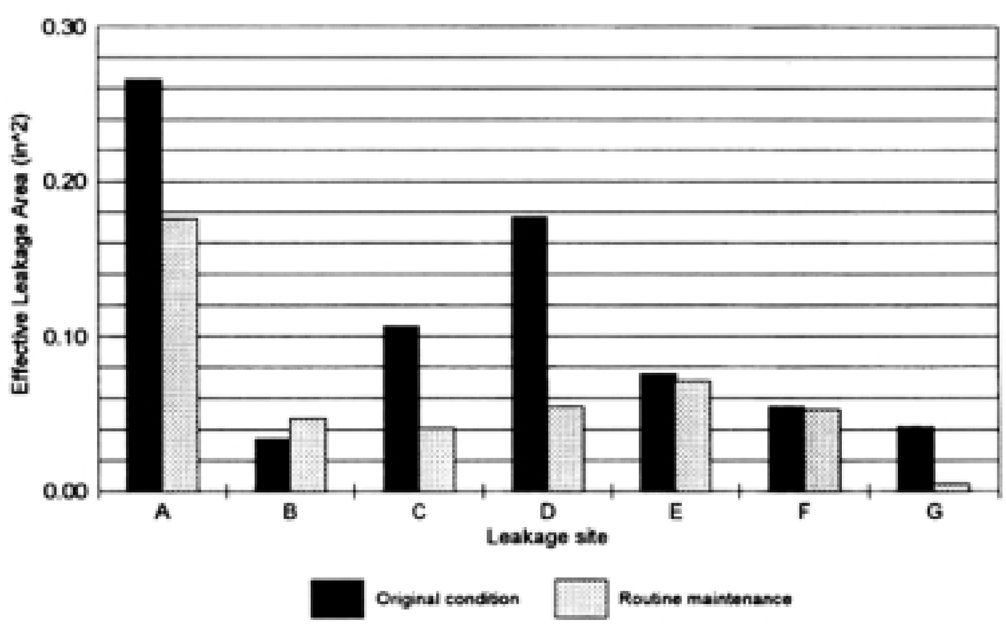
Leakage rates did not appear additive once again, as noted in the previous section. Effective leakage areas (ELA’s) were calculated for leakage sites in both the original condition window and after routine maintenance. Leakage site ELA’s are shown in Figure 7. Effective leakage areas appear more additive than leakage rates, overestimating the whole window value by an average of 30%, as opposed to a 65% overestimation when using leakage rates. An anomaly serving to increase overestimation based on ELA’s was noted at the meeting rail (site B). Air leakage increased by 25% after routine maintenance, but was expected to remain relatively constant, as leakage rates did at sites E and F. That

Figure 6: Lab window A sash leakage rates, original condition versus routine maintenance



increase was not investigated further as the purpose was to check the approximate additive nature of ELA's.

Figure 7: Leakage site ELA's for lab window A, original condition versus routine maintenance



5d iii. Laboratory tests of Bi-Glass System upgrade

Three windows at 40 Nash Place (all single-hung, pin-type windows) and one lab test window (a double-hung, pulley-type window) received the Bi-Glass System window upgrade. Lab window B differed from the Nash Place windows by not being fitted with the double-pane insulating glass insert. The double-pane insert was excluded from the lab window as non-infiltrative losses were investigated by computer simulation rather than lab testing.

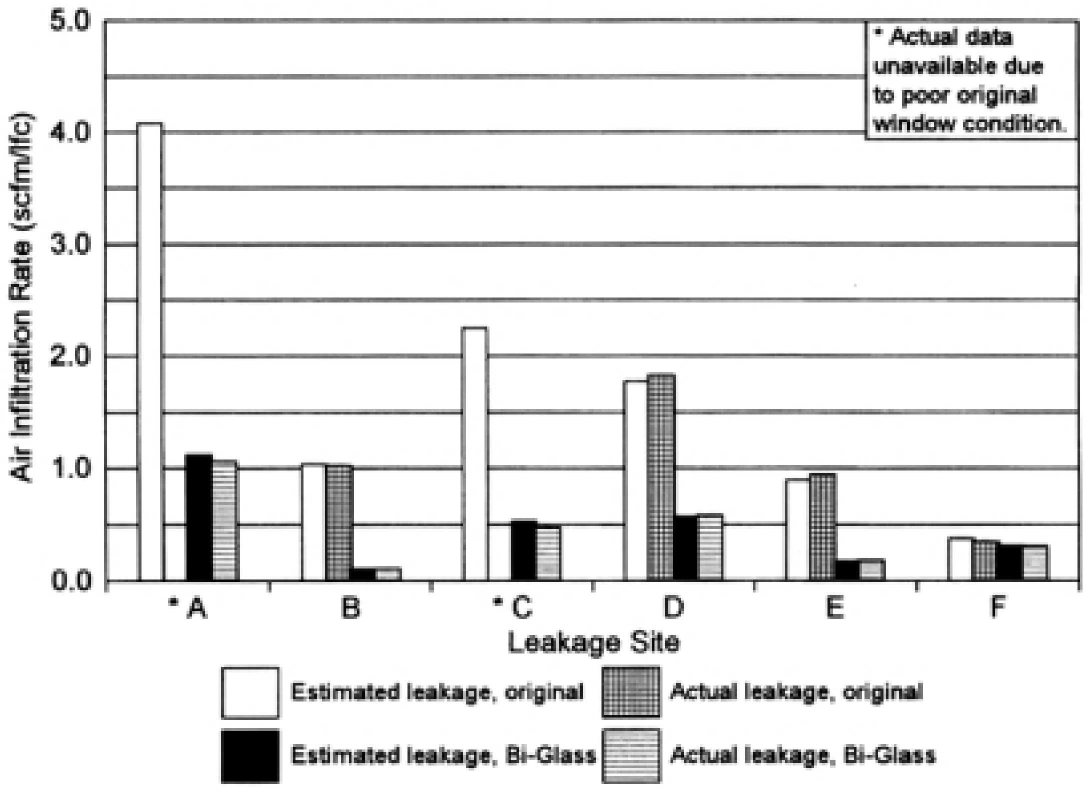
The lab window was a pulley-type window with attached window weights. The Bi-Glass System upgrade involved cutting window weight ropes while leaving the weights in the window weight cavity. Pulleys were removed with fiberglass insulation stuffed into the window weight cavity through the pulley opening. The pulley opening and window weight access panel were sealed with duct tape prior to installation of the jamb liners. Vinyl jamb liners were cut to fit the existing jamb and had an adhesive foam backing to reduce air movement between the jamb and jamb liner. The foam backing was compressed by the sash as well as three support screws on each jamb liner. The existing sash were routed to accept vinyl jamb liners and double-pane insulating glass inserts. Although not present in the lab window, muntins present in a divided light would be trimmed to fit over the replacement glass, mimicking the look of a true divided light. The top rail of the upper sash and bottom rail of the lower sash were routed to accept a silicone weatherstripping bead, improving the seal at the head and sill junctions. A third silicone weatherstripping bead was inserted into the lower rail of the top sash to tighten the meeting rail junction, along with a new vinyl latch type lock attached near the meeting rail center.

Air leakage rates in terms of sash leakage (Qs as scfm/lfc) for various leakage sites of lab window B and its Bi-Glass System upgrade were compared. Figure 8 shows the relative improvements made using the Bi-Glass System. It should be noted that 0.30 inches of water pressure could not be attained for some sections of the lab window in its original condition. Also shown in Figure 8 are extrapolated versus actual values where attainable, illustrating the proximity of extrapolated values to actual values.

The Bi-Glass upgrade made significant improvements to the efficiency of the lab window at all locations except through the outside edge of the exterior trim (F in Figure 8). This site represented extraneous air coming through the rough opening (Q_e), passing into the test zone through the window weight cavities. As mentioned previously, the Bi-Glass System window renovation stuffed fiberglass insulation into the window weight cavities to decrease air leakage. The small decrease in air leakage through the rough opening supports the findings of an earlier Canadian study on the effectiveness of rough opening sealing methods (Proskiw, 1979). That study showed fiberglass insulatiion stuffed into rough openings was a poor sealing method.

Extrapolated leakage rates for lab window B were over 4.0 scfm/lfc, based on regression coefficients for sash leakage at 0.30 inches of water pressure. The Bi-Glass System

Figure 8: Lab window B, relative air leakage reductions at 0.30 in. H_2O due to Bi-Glass Systems upgrade



A - Leakage rate through the total window
B - Leakage rate through the meeting rail
C - Leakage rate through the upper sash with the meeting rail sealed
D - Leakage rate through the lower sash with the meeting rail sealed
E - Leakage rate through the sill junction
F - Leakage rate through the outside edges of the exterior trim

upgrade decreased the sash leakage rate to 1.1 scfm/lfc, a 360% reduction. While the improvement was significant, the air leakage rate was well above the industry standard for new windows (0.37 scfm/lfc at 0.30 inches of water pressure).

A chemical smoke generator was employed to observe air currents to further identify leakage sites in the Bi-Glass System upgrade. Air was observed easily infiltrating the jamb/jamb liner junction, as well as the head/upper sash junction. Leakage through the jamb/jamb liner junction implied the failure of the jamb liner foam backing to perform as intended. The same was true for the silicone weatherstripping bulb in the head/upper sash junction.

5d iv. Lab Testing Summation

Testing of the two lab windows revealed the perimeters of both sash to be major air leakage sites. Routine maintenance was shown to significantly reduce air leakage if the original condition window was in poor condition, but the result was still a loose window allowing substantial air leakage. The Bi-Glass System upgrade significantly reduced air flow for the whole window but did little to reduce air flow through the window weight cavity. Both the weatherstripping at the head junction and the foam backing on the jamb liners allowed air flow when viewed with a chemical smoke generator, implying a poor fit.

5e. Correlation of Induced Air Leakage to Natural Infiltration Rates

Window air leakage rates, as measured by fan pressurization in the field, do not directly correspond to natural infiltration rates through those windows during the heating season. Natural infiltration rates vary over time as a result of a combination pressure differential, induced by wind speed and direction along with interior/exterior temperature differences.

The sash and extraneous air leakage rates for each window were used to extrapolate induced leakage rates at 0.016 inches of water pressure, the assumed heating season driving pressure for natural infiltration. Based on field measurements, 30% of the averaged extraneous air was assumed to be exterior air and was added to the sash leakage rate. This whole window infiltrative leakage rate was converted to a whole window effective leakage area (ELAtot) at 0.016 inches of water pressure. The value was used in the LBL correlation model to convert the ELAtot to a natural infiltration rate (Q_{nat}) for each type of window and upgrade. Parameters typical of the Vermont climate and affordable housing were used in the model. Table 16 lists the assumed parameters used in the LBL model.

Table 16: Parameters assumed typical of Vermont, used in the LBL correlation model

Housing Parameters			**Weather and Terrain Parameters**		
Volume		30,000 ft^3	Terrain Parameters	y	0.23
Roof Height		19 ft		a	0.73
Leakage area	ceiling	33%	Shielding Coefficient		0.24
	floor	33%			
	walls	34%			
Interior Temperature		68^{o}F			

The Vermont heating season was assumed to extend from the month of October through April. Mean monthly temperatures and wind speeds throughout the heating season for Burlington, Vermont were used to determine the overall heating season natural infiltration rate. The LBL model was placed in a spreadsheet and run using a personal computer. An example of the computer print-out is found in Appendix G. Table 17 summarizes the predicted natural infiltration rates (Q_{nat}) based on results of the LBL correlation for each assumed window and window upgrade. Infiltration rates are based on whole window infiltration which includes the exterior air component.

It should be restated that LBL values shown for Q_{nat} were based on whole window effective leakage area (ELA_{tot}) which was defined to include a calculated volume of exterior air for the purposes of this study. The LBL correlation model was also used in a manner for which it was not intended. Therefore, all values based on the LBL model should not be viewed as absolutes, but rather as relative values to one another. It should also be noted that

Table 17: Estimated natural infiltration flow rates (Q_{nat}) for the period October through April

Window		Site ID	n	Storm open ELA$_{tot}$ (in^2)	Storm open Q_{nat} (scfm)	Storm closed ELA$_{tot}$ (in^2)	Storm closed Q_{nat} (scfm)
Typical with storm window		---	---	---	---	1.48	2.07
Tight with storm window		---	---	---	---	0.85	1.19
Loose with no storm window		---	---	2.77	3.87	---	---
Original sash, vinyl jamb liners; no weatherstripping		12	7	3.05	4.26	1.48	2.07
Original sash; vinyl jamb liners; weatherstripping at sill, head junctions		13	8	2.79	3.90	1.74	2.43
Original sash; vinyl jamb liners; weatherstripping at sill, head, meeting rail junctions		7	19	1.13	1.58	0.83*	1.16*
Bi-Glass System		2	3	1.04	1.45	0.71	0.99
Coiled spring balances; weatherstripping at sill, head junctions, wooden storm windows weatherstripping		16	2	---	---	3.43	4.80
Rib-type weatherstripping; V-strip at meeting rail, pulley seals, top sash painted in place; new triple track storm window frames caulked in place		17	3	1.09	1.52	0.91	1.27
V-strip weatherstripping around lower sash, top sash painted in place, existing triple track storm window frames caulked in place		19	2	0.71	0.99	0.60	0.84
Polyflex T-slot weatherstripping around upper and lower sash		10	1	0.71	0.99	0.81	1.13
Interior storm window with spring loaded metal frame		10	1	4.25	5.94	0.39	0.55
Fixed aluminum storm window, removable pane		10	1	4.55	6.36	0.64	0.90
Aluminum triple track storm window		10	1	4.25	5.94	0.86	1.21
Reglazed and painted with new aluminum triple track storm windows		14	6	2.16	3.02	0.45	0.63
Interior plexiglass storm windows held by magnetic strips		15	4	2.25	3.15	0.27	0.38
Top sash painted in place; bronze V-strip weatherstripping; old aluminum triple track storm frame caulked in place		19	2	0.71	0.99	0.60	0.84
Replacement sash	Includes 18	3, 12, 13, 18	11	0.75	1.05	---	---
	Excludes 18	3, 12, 13	9	0.87	1.22	0.78	1.09
Replacement window inserts	Includes 16	6, 7, 11, 16	14	0.29	0.41	---	---
	Excludes 16	6, 7, 11	13	0.21	0.29	---	---

*Data based on one window with exterior wooden storm sash. See text for explanation.

most window upgrades have very low sample populations (n) and should not necessarily be regarded as typical of the upgrade type nor viewed as statistically significant.

Values for both ELA_{tot} and Q_{nat} for site 7, storm closed, should be viewed with a large degree of caution. The site had only one wood sash storm window (7B 2) in place with a poor fit to the exterior trim. The averaged site value for leakage with storm windows in place was based on the ratio of extrapolated sash leakage values for the one window tested with and without a storm at 0.30 inches of water pressure. This ratio (0.66:1) was multiplied by the average ELAtot for storm windows open (off) to estimate the effect of storms covering all site windows. The LBL correlation was run using these manipulated values and is subject to speculation.

An anomaly was noted for the site 10 window weatherstripped with Polyflex. Air leakage increased when the fixed wooden storm was in place, a situation that should not have occurred. A cause for this anomaly was not determined.

Replacement sash included two double-pane insulating glass windows not fitted with storms at site 18. The two data values in Table 17 reflect both the inclusion and exclusion of those windows from the group average. It can be seen that these two windows played a major role in reducing average ELA_{tot} and Q_{nat} values with storm windows open. A large portion of the difference was in the volume of extraneous air measured during the pressurization test. Windows at site 18 had an excessive amount of work done to reduce extraneous air leakage and were not considered typical renovations.

The opposite situation applies for replacement window inserts where all but one window showed very low extraneous air leakage values. The one window at Site 16 was considered atypical of the general upgrade category. Again, two LBL correlation values are shown in Table 17 for replacement window inserts, one including window 16G, and the other excluding it.

5f. Thermography

Thermographs were taken of two upgrade options in February 1996. Interior plexiglass storm windows at 4 Occom Ridge, Hanover, NH (site 15) were compared to an adjacent window with the plexiglass storm panel removed. This window also had rope caulking around the operable perimeter and pulleys to prevent drafts as well as an aluminum triple track storm window in place. The caulking was partially removed to demonstrate its ability to reduce air infiltration. The resulting thermograph (Figure 9, page 53) showed the rope caulking reduced air infiltration, keeping the sill a minimum of 8°F warmer than the lower sash. The black corner at the sash/frame junction revealed cold air infiltration through the window. It can be seen that the caulking effectively prevents infiltration around the operable perimeter. Upon pressurization testing, these windows were discovered to be very leaky when the interior storm window and rope caulking were removed.

The second thermograph (Figure 10, page 54) shows the aforementioned window with an adjacent plexiglass interior storm window in place. The surface temperature of the window without an interior storm ranged from below 50°F to 62°F. The surface temperature of the interior plexiglass storm ranged from 58°F to 66°F, with the vast majority of its surface area being in the 60°F to 66°F range. The coldest section was at the storm window/sill junction where the effects of conduction would be seen.

Images of three other windows were taken in Robinson Hall of Dartmouth College. One of these was a Bi-Glass System upgrade while the other two windows were in their original condition. Both of the original condition windows had triple track aluminum storm windows, but one window was missing the lower panel. Where the lower panel should have been was a sheet of plexiglass resting against the window. Figure 11 (page 55) shows this window, with the warmest surface area (65°F) corresponding to the location of the plexiglass panel. The center of glass surface temperature for this window with effectively no storm window, was between 55°F and 60°F.

Figure 12 (page 56) shows the window with the operable triple track storm panels in place. Its average surface area was approximately 65°F, warmer than the window with no effective storm window.

Figure 13 (page 57) shows the Bi-Glass System replacement with its double-pane insulating glass. The surface temperature of the glass ranged from 70°F near the sill to 85°F in the center of glass.

Any conclusions based on the Robinson Hall thermographs must consider the effect of unequal space heating. As in most old buildings, hot water radiators were situated beneath the windows. The temperature regimes of the radiators varied considerably from window to window with the coolest radiator being below the coolest window and the hottest radiator being directly beneath the Bi-Glass System upgrade. The radiators likely had a significant effect on the glass surface temperatures, but it is unlikely either of the other two windows would have achieved as high a center of glass temperature as the Bi-Glass window.

Figure 9: Thermograph of sash infiltration reduction due to rope caulking

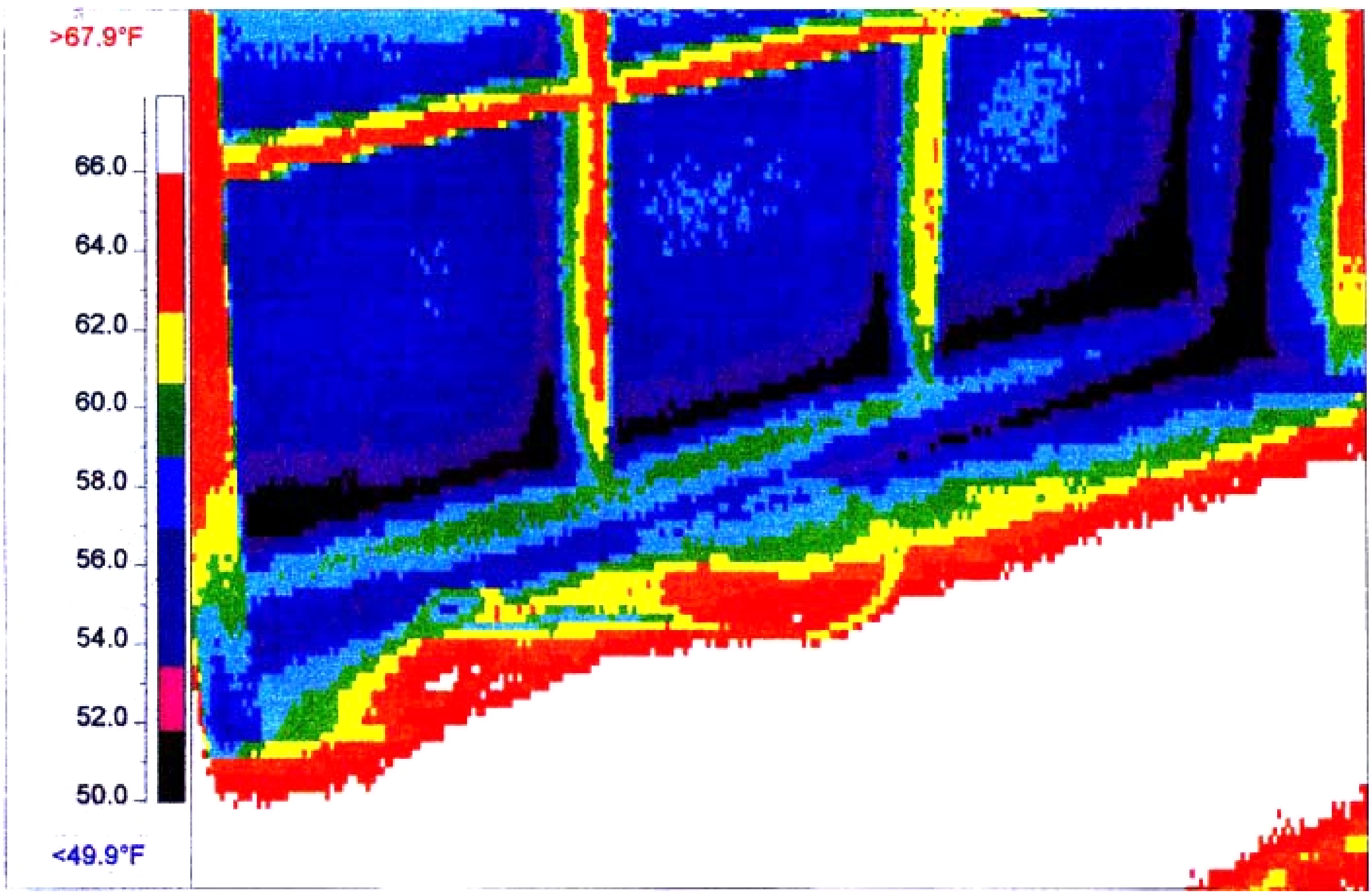


Figure 10: Thermograph of plexiglass interior storm window adjacent to window with interior storm removed

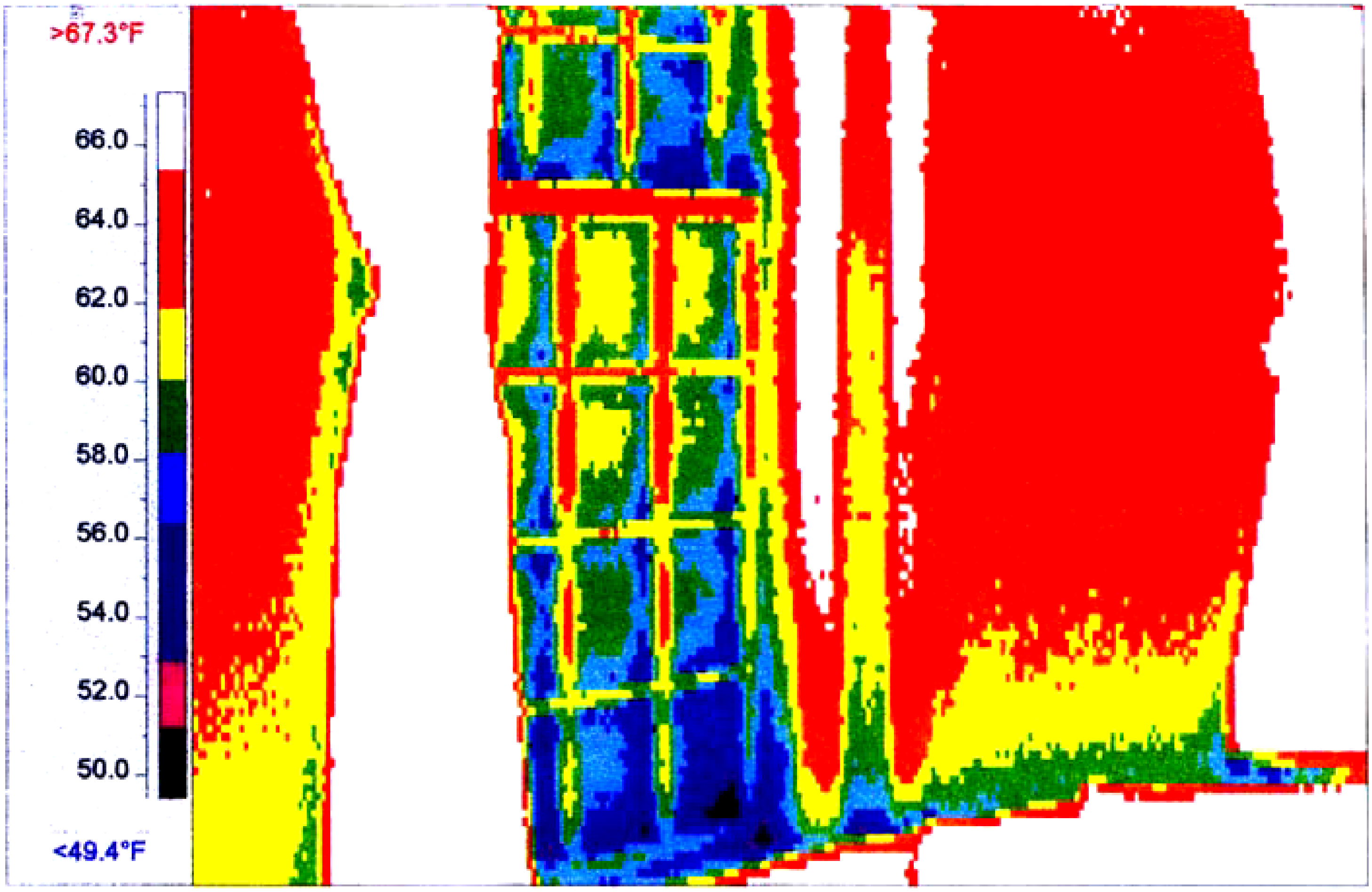


Figure 11: Thermograph of Robinson Hall window with no effective storm attached

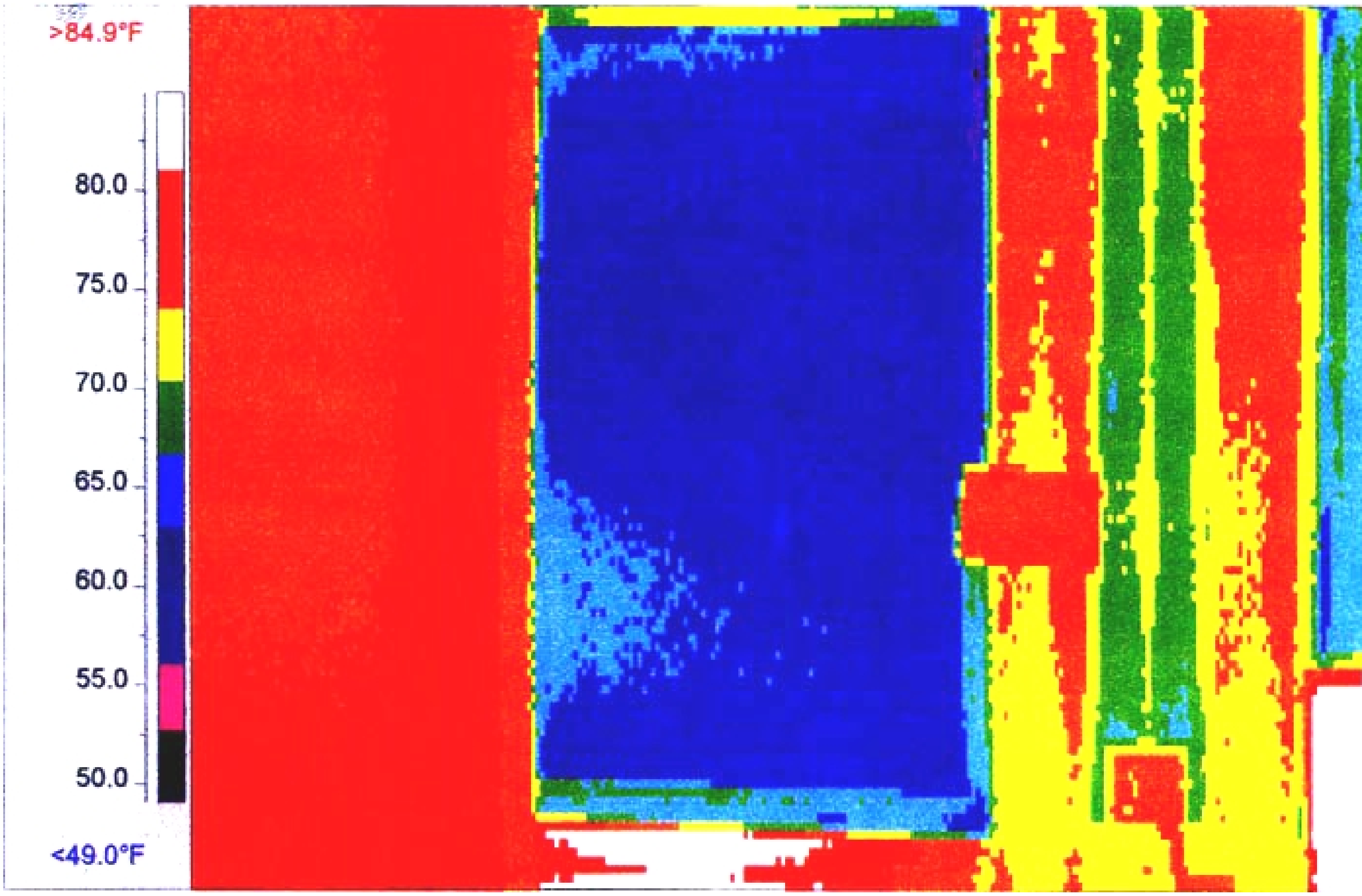


Figure 12: Thermograph of Robinson Hall window with aluminum triple track storm windows in place

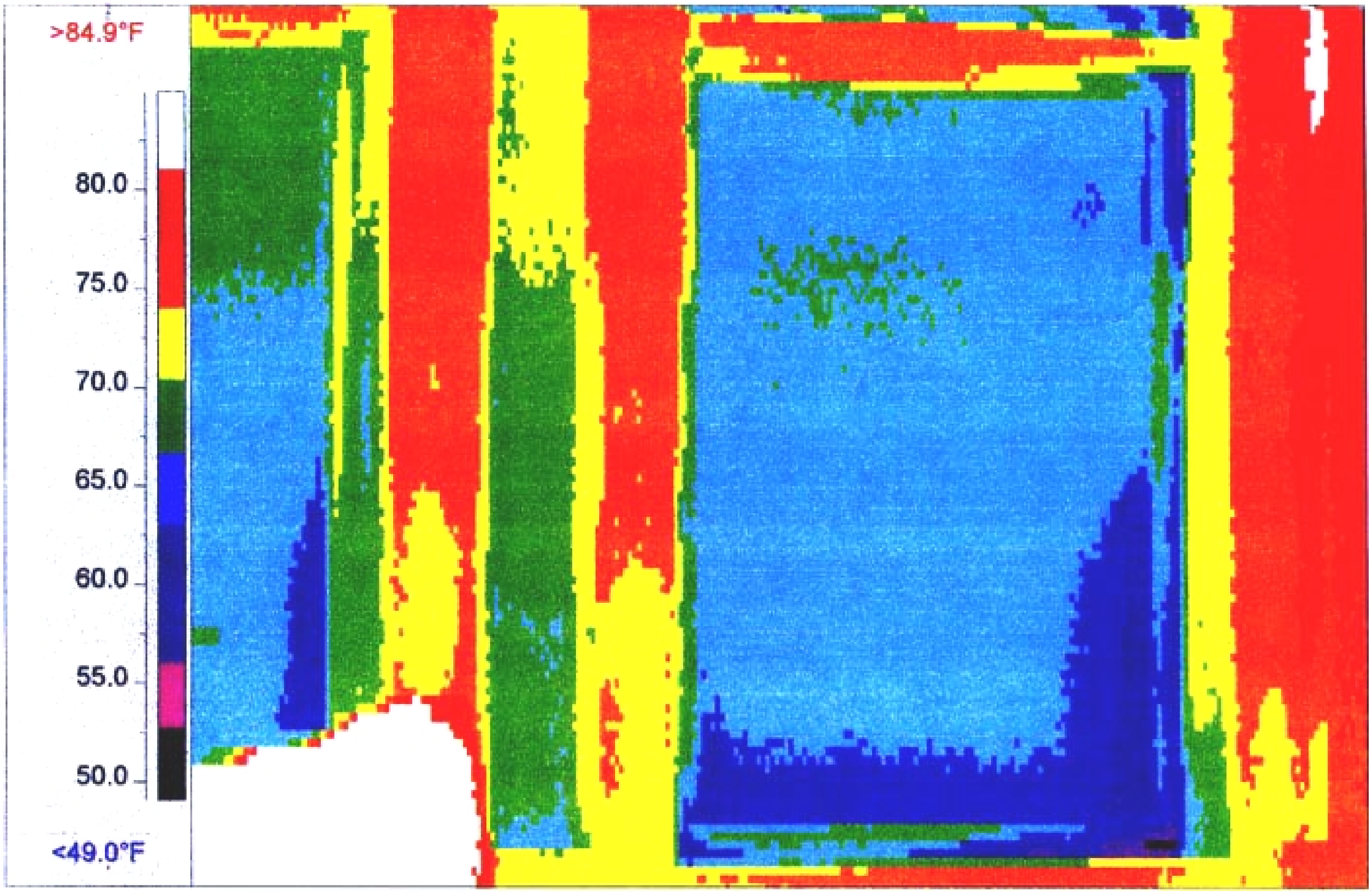
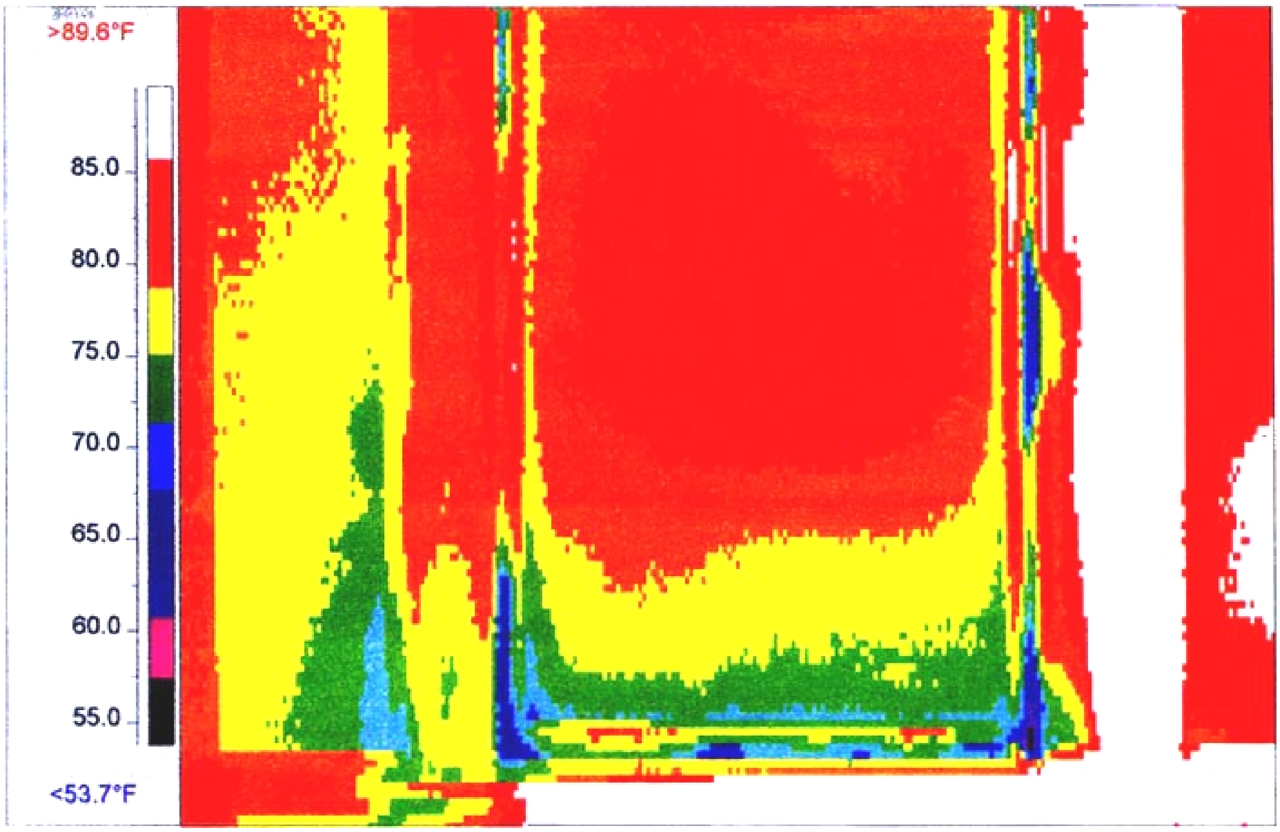


Figure 13: Thermograph of Robinson Hall window with Bi-Glass System upgrade



5g. Energy Savings Attributable to Upgrades

Average seasonal heating infiltrative rates (Q_{nat}) were converted to infiltrative thermal loss rates per window (L_{inf}) by multiplying Q_{nat} by the heat capacity of air:

$$L_{inf} = Q_{nat} * Cp_{air}$$

$$L_{inf} = Q_{nat} * \frac{0.018\,Btu}{ft^3 * {}^oF} * \frac{60\,min}{1\,hr}$$

Non-infiltrative loss rates (U-values) were converted to non-infiltrative thermal loss rates per window (L_u) by multiplying the U-value by the area of an assumed typical window (15 ft^2). Whole window infiltrative and non-infiltrative loss rates were summed to determine the "effective thermal loss" of a window (L_{eff}):

$$L_{eff} = L_{inf} + L_u$$

Annual heat loss per window (L_{yr}) in millions of Btu's (MMBtu) was calculated by multiplying the "effective thermal loss" (Li,) by the average number of degree-day units in Burlington, Vermont:

$$L_{yr} = L_{eff} * 7744 \ degree\text{-}days * \frac{24\,hr}{day} * 10^{-6}$$

The annual heating cost per window in 1996 dollars was calculated by using the fuel cost, fuel heat capacity, burner efficiency, and annual heat Lyr in the following formula:

$$C_{win} = \frac{(fuel\ cost\ per\ unit) * (annual\ heat\ required) * 10^6}{(fuel\ heat\ capacity\ per\ unit) * (heating\ system\ efficiency)}$$

$$C_{win} = \frac{\$0.90/gal * L_{yr} * 10^6}{(138{,}600\,Btu/gal) * 0.75}$$

First year annual heating costs per window were based on number 2 fuel oil as an energy source at $0.90/gallon with a 75% furnace efficiency. Table 18 shows estimated first year annual heating costs in 1996 dollars attributable to the assumed existing window types. Estimated first year costs for each upgrade were compared to those costs estimated for the assumed typical, tight, and loose windows. First year annual costs and savings for each upgrade in 1996 dollars are also shown in Table 18.

It is critical to note once again that in this study, the LBL correlation model was used for

Table 18: Estimated first year annual savings in 1996 dollars due to window upgrades

Window Upgrade Description	Heating Cost per Window Upgrade	Annual first year savings per upgrade as compared to a:		
		Tight Window	**Typical Window**	**Loose Window**
Tight window with storm	$14.38	---	---	---
Typical window with storm	$15.91	---	---	---
Loose with no storm	$28.93	---	---	---
Original sash, vinyl jamb liners; no weatherstripping	$15.91	***	**0.00**	$13.00
Original sash; vinyl jamb liners; weatherstripping at sill, head junctions	$16.53	***	***	$12.40
Original sash; vinyl jamb liners; weatherstripping at sill, head, meeting rail junctions	$14.33	$0.05	**$1.60**	$14.60
Bi-Glass System	$13.55	$0.80	**$2.40**	$15.40
Rib-type weatherstripping; V-strip at meeting rail, pulley seals, top sash painted in place; new triple track storm windows, caulked	$14.52	***	**$1.40**	$14.40
V-strip weatherstripping around lower sash, top sash painted in place, existing triple track storm windows caulked in place	$13.77	$0.60	**$2.10**	$15.20
Polyflex T-slot WS around upper and lower sash	$14.27	$0.10	**$1.60**	$14.70
Reglazed and painted with new aluminum triple track storm, caulked to trim	$13.40	$1.00	**$2.50**	$15.50
Interior plexiglass storm window held by magnetic strips	$13.00	$1.40	**$2.90**	$16.00
Interior storm window with spring loaded metal frame	$13.30	$1.10	**$2.60**	$15.70
Replacement sash with storm window	$14.20	$0.20	**$1.70**	$14.70
Low-e replacement sash with storm window*	$10.83*	$3.55*	**$5.10***	$18.10
Replacement sash with low-e storm window*	$12.27*	$2.10*	**$3.60***	$16.70*
Replacement sash with double-glazed insulating glass	$13.65	$0.70	**$2.30**	$15.30
Replacement sash with double-glazed low-e insulating glass*	$10.27*	$4.10*	**$5.60**	$18.70*
Replacement window inserts with double-glazed insulating glass, excluding 16G	$12.33	$2.10	**$3.60**	$16.60
Replacement window inserts with low-e double glazed insulating glass*	$8.95*	$5.40*	**$7.00***	$20.00*

***Denotes negative values for savings
*Denotes window upgrades not encountered during field testing

a purpose for which it was not intended. The estimated first year savings shown in Table 18 and discussed below are relative to each other only in the context of this study and are not absolute values. The values in Table 18 given an indication of the relative energy cost savings attributable to each window upgrade as compared to energy costs associated with assumed windows. These values should not be interpreted as actual energy savings realized. They may be used to rank upgrades or to interpret which are comparable in terms of energy savings.

Estimated first year annual energy savings realized from a field tested upgrade ranged from zero to a maximum of $3.60 per year per window as compared to annual energy costs for a typical existing window. The maximum value was attained by using a replacement window insert. Although not field tested, using a low-e, double-pane insulating window insert showed an estimated first year annual energy savings of $7.00 per window per year. First year savings compared to an assumed loose window ranged from $12.00 to $16.00 for tested field tested upgrades and up to $20.00 for low-e insulated glass replacement window inserts. Again, all values are relative to one another and not absolute values. Blocks with asterisks represent negative values in terms of savings. Negative values may partially be the result of varying extraneous leakage rates at each site.

There is a large range of variation in estimated first year annual savings by upgrade, but a grouping of upgrades by glazing type reveals field tested double-glazed upgrades show significantly larger savings than single-glazed at a 95% confidence level. It should be noted that the double-glazed windows included 14 replacement window inserts which significantly reduced exterior air infiltration. Therefore, differences in savings as discussed below are not solely attributable to double-glazing.

All field tested double-glazed upgrades were averaged together yielding an estimated first year annual savings average of $2.90 per year per window versus a $1.40 average per year per single-glazed window as compared to the assumed typical window. When compared to the assumed loose window, averaged savings were $16.00 per year per double-glazed window versus $14.00 per year per single-glazed window. Greater first year estimated annual savings would be realized by the addition of low-e glass.

5h. Estimated Costs for Upgrade Purchases and Installation

Along with estimated savings in first year energy costs, initial materials purchase and installation costs in 1996 dollars were considered for the upgrade options. Table 19 shows estimated costs associated with upgrade options as of August 1996 including labor, priced at $20 per hour. The estimated cost of a window upgrade and its installation may be compared to the relative size of estimated savings in first year energy costs as found in Table 18. It should be noted again that the estimated first year savings in Table 18 are not absolutes, but should be used only as a means of comparing one upgrade to another. Therefore, values in Table 18 may not be used to calculate payback periods for a window upgrade when combined with estimated costs from Table 19. No provisions have been made in this study to investigate the life span of any window upgrade, nor have provisions been made to estimate how energy savings change over time.

A further issue in window renovations was that of lead paint. In order to retain an original sash, federal and state regulations mandate lead abatement if lead paint was used on the sash. Lead abatement added an additional $125 to $150 cost per window, sums that are not reflected in Table 19. The inclusion of this additional cost for original sash lead abatement would make the first four options approximately equivalent in price.

Table 19: Estimated window upgrade costs as of August 1996, including materials and installation but excluding lead abatement costs

Upgrade option			Materials	No. Reqd	Unit Cost	Total	Labor Hours	Labor Cost @ $20/hr	Total Cost
V-strip + cam locks, fix upper sash in place, rehab storm			Bronze V-strip	1 set	$5.00	$5.00	0.50		
			Caulk			1.00	0.10		
			Cam Locks	2	1.00	2.00	0.25		
			Pulley seals	2	0.75	1.50	0.10		
			Rope for pulleys	8 ft	0.10	0.80	0.25		
			Window putty	0.25	3.00	0.75	0.50		
			Paint prep			0.50	0.50		
			Storm window rehab			10.00	0.50		
					Total	$21.55	2.70	$54	$76
Vinyl jamb liners, rehab storm			Caldwell DH100 jamb liners	1	$12.00	$12.00	1.50		
			Silicone bulb WS	6	0.90	5.40	0.50		
			Sash lock	1	1.00	1.00	0.25		
			Foam for cavity	0.5	12.00	6.00	0.50		
			Int. trim adjustment	5	1.00	5.00	0.50		
			Int. trim paint			2.00	0.50		
			Window plow	0.2	12.00	2.40	1.00		
			Window putty	0.25	3.00	0.75	0.50		
			Paint prep			0.50	0.50		
			Storm window rehab			10.00	0.75		
					Total	$45.05	6.50	$130	$175
Brosco double-hung single-glazed	6/6	$110	Sash lock	1	1.00	1.00	0.25		$210
	2/2	$114	Foam for cavity	0.5	12.00	6.00	0.50		$214
	1/1	$79	Int. trim adjustment	5	1.00	5.00	0.25		$179
with low-e glass	6/6	$174	Int. trim paint			2.00	0.50		$274
	2/2	$178	Storm window rehab			10.00	0.50		$278
	1/1	$143			**Total**		5.00	$100	$243
Marvin E-Z Tilt double-hung, double-glazed	6/6	$520							$615
	2/2	$319							$414
	1/1	$168	Foam for cavity	0.5	12.00	6.00	0.50		$263
with low-e glass	6/6	$594	Int. trim adjustment	5	1.00	5.00	0.25		$689
	2/2	$372	Int. trim paint			2.00	0.50		$467
	1/1	$211	New screen or rehab storm			10.00	0.50		$306
Marvin Tilt-Pac with low-e glass	6/6	$499			**Total**		4.75	$95	$594
	2/2	$396							$491
	1/1	$222							$317
Harvey Tru-Channel triple track storm window			Standard glass $70						$100
			Low-e glass $87		**Total**		1.5	$30	$117
Fixed upper, removable lower panel storm window			Standard glass $200						$220
			Low-e glass $240		**Total**		1.0	$20	$260
Wood exterior storm window			Standard glass $110						$125
			Low-e glass $140		**Total**		0.75	$15	$155
Allied Window magnetic interior storm window			Standard glass $110						$125
			Low-e glass $150		**Total**		0.75	$15	$65
Alternative Window interior spring loaded storm window			Standard glass $115						$125
			Low-e glass $150		**Total**		0.5	$10	$160
Bi-Glass System upgrade						$200-$250 depending on size			$225
Weather Shield "Custom Shield" wood replacement window insert						$500			$500
Vinyl replacement window insert						$200-$300 depending on quality			250

Ancillary notes to Table 19

Window Rehab Option Costs
NOTES
1 Labor and materials do not include paint cost, as that is assumed to be the same for all treatments
2 For existing sash that are retained, 1 hour total assumed for putty and paint prep, and $10 + 1/2 hour for storm rehab
3 Costs are as of August, 1996
4 Costs do not include the following, which may be required in some cases.

sales tax on materials	5%	Vermont sales tax rate
lead paint abatement	$135	typical cost
total reglaze of sash	$25	assumes re-using glass
painting	Range from $25 to $50	
Storm window glass or other repair	Varies	
Contractor markup, OH & P	Range from 10% to 20%	
Total interior trim replacement	$25	
If no pulley cavity for all options except #1.	($22)	deduct if no window weight cavity
Additional adjustment of opening or trim	Varies	

[1] For added ~$50, available with "Poly-Paint" 10-yr warranty, but can not trim window to fit. Price is for 5'-2" height-for custom size of 5'-0" add $50.
[2] Note: price includes prepainted sash&frame, 10-yr warranty paint, 1/1
[3] Mark-up is applied to materials and to labor costs

Replacement Sash Costs		Sash Onl	with Channels	
Brosco single glass				
2-8*5-2 sash opening	6/6	$95.09	110.39	
	2/2	$99.00	114.3	(special order)
	1/1	$79.38	94.68	
	Side channels	$15.30		per pair
Brosco insulated glass	1/1	$106.43	121.73	
true divided lites	2/2, 6/66 not available			
Brosco energy panels				
low-e glass		$63.20		
Marvin Tilt-Pack, low-e	8/8			
insulated glass	6/6	$499.23		
2-8 x 5-2 sash opening	2/2	$395.53		
true divided lites	1/1	$221.33		
includes channels				

Interior spring-loaded storm			
Alternative Window Co.	$115.00	wholesale price	(retail $150)
low-e glass, add	$35.00	wholesale price	
1/3 hour estimated labor	$6.67		
TOTAL	$156.67		

Allied Window Co — 197 contractor's price
Top fixed, bottom removeable — based on 10 or more windows, standard color
Exterior storm, Model HOL — Low-E adds $40

Harvey Tru-Channel Storms — 69.5 wholesale price
low-e glass, add — 17 wholesale price

Weathershield (price from Huttig)		single	double	low-e
3-0 x 5-0	6/6			
wood, primed	2/2			
with tilt-turn channels	1/1			

Magnetic interior storm window
form Allied window — 110
U-channel at head — Low-E adds $40
Vee-strip weatherstrip at sill

6. ANALYSIS AND DISCUSSION

Estimated savings for first year energy costs show little variability between upgrade options when compared to the estimated energy costs of a typical window. The cost variability of upgrade options decreases significantly when lead abatement of original sash is included. Estimated first year savings are also of very small magnitude when compared with typical windows. It is therefore not worthwhile to base upgrade decisons solely or even primarily on energy considerations. Other non-energy considerations should play a greater role in deciding whether to upgrade or replace existing windows. Energy performance should be included as part of the decision making process, however. Life cycle costs of window upgrades should also be considered, including maintenance costs over time.

Visual examination of windows gave no clear indication of their leakage classification as tight, typical, or loose windows. However, the lack of an easy method of deducing air leakage rates for a window without resorting to fan pressurization was unimportant given the leaky nature of the majority of original condition windows field tested.

Fan pressurization data showed pulley-type windows allowed significantly larger rates of exterior air leakage than pin-type, illustrating the importance of reducing air infiltration through the rough opening. The significance of the exterior air contribution to a window's total heating load was revealed throughout the study, with exterior air accounting for a large percentage of the infiltrative thermal losses. Reducing exterior air infiltration should be a part of any window renovation, whether the renovation is an original sash upgrade or a replacement sash.

The inclusion of an exterior air component in window infiltrative thermal losses increased the estimated annual window energy costs for all upgrades, approximating actual thermal losses through a window and its surround more closely than thermal losses through the window sash alone. The contributing role of exterior air to the heat load of a tight window is more significant than to the heat load of a loose window as it represents a larger percentage of the overall infiltrative losses for a tight window. Any renovation will serve to reduce sash air leakage, thereby increasing the relative significance of exterior air infiltration unless steps are taken to simultaneously reduce exterior air infiltration.

6a.Infiltration Reduction in Windows Tested Pre- and Post-upgrade

A total of 26 windows at six sites were field tested prior to and after window renovations. Four of these original condition windows were of sufficient leakage to prevent maximum pressurization and were not considered. Of the remaining 22 windows, 17 retained the original storm after renovation or had no storm window when tested. The other five windows were fitted with interior storm windows. Average sash and extraneous leakage characteristics for the 17 windows with either the original storm window or no storm are listed by site in Table 20, with storm windows off or open. The same characteristics for the five interior storm windows are also listed, but with storms removed and in place.

Table 20: Averaged leakage characteristics of windows prior to and post renovation

Site ID	Window Upgrade	n	Pre-upgrade			Post-upgrade			ELA_{tot} % Dec
			$ELA_{s\ x\ 19}$ (in^2)	$ELA_{ext\ x\ 19}$ (in^2)	ELA_{tot} (in^2)	$ELA_{s\ x\ 19}$ (in^2)	$ELA_{ext\ x\ 19}$ (in^2)	ELA_{tot} (in^2)	
2	Bi-Glass System	3	2.75	0.57	3.32	0.71	0.33	1.04	70%
3	Replacement sash	2	1.07	0.70	1.77	0.32	0.24	0.56	70%
6*	Vinyl inserts replacement	3	3.42*	0.63*	4.05*	0.04	0.10	0.14	95%
7	Original Sash with vinyl jamb liners	9	2.18	0.55	2.63	0.81	0.32	1.13	60%
			Interior storm window removed			Interior storm window in place			
10	Spring loaded	1	4.05	0.20	4.25	0.25	0.19	0.44	90%
15	Magnetic stripping	4	1.42	1.67	3.09	0.01	0.23	0.24	90%

* Original windows at Site 6 were single-hung, partially accounting for this relatively large value. As a double-hung window, $ELA_{s\ x\ 19}$ would have been 1.96 in^2, $ELA_{ext\ x\ 19}$ would have equaled 0.36 in2, for an ELA_{tot} of 2.32 in^2.

All pre- and post-test windows retained the original sash with the exception of site 6. Upgrades at this site were vinyl replacement window inserts and were expected to perform significantly better than the original condition windows.

Interior storm windows show the greatest reduction in ELA_{tot} as discussed previously. Three of the four interior storm windows at site 15 allowed zero sash flow within the limits of resolution for the pressurization device flow meter, largely accounting for the significant reduction in $ELA_{s\ x\ 19}$

There is a significant reduction in ELA_{tot} between windows in their original condition and any upgrade, at a confidence level of 99.9%. All relative percentages should be viewed with caution, due to the low number of samples in each population. The only site approaching a significant population number is site 7 with nine windows. The average reduction in ELA_{tot} for that site was 60%.

Extrapolated values for sash leakage rates were also compared, with upgrades again showing significant reductions at a 99.9% confidence level. Extrapolated values were used due to the leaky nature of the original windows.

3b. Improvements Due to Storm Window Upgrades

The use of exterior storm windows provided two energy benefits, significantly reducing sash leakage when the storm frame was caulked to the exterior trim and providing a second layer of glazing. The storm window as a second glazing layer had a significant effect on reduction of non-infiltrative thermal loss rates during modeling with WINDOW 4.1.

A significant improvement was seen with the use of new aluminum triple track storm windows when frames were caulked to the exterior trim. Four prime windows showed a reduction of 75% in sash leakage when the new storms were closed, while another site with three year old storm windows showed a 35% reduction. It can be assumed the average value for sash leakage reduction is between those bounds. A comparison of 24 original condition windows with aluminum triple track storms in open and closed positions, showed a 46% reduction in sash leakage. It is likely that the use of new aluminum triple track storm windows with frames caulked would exceed original window condition sash leakage reduction, being closer to the 75% reduction seen with the use of new storm windows. Differences between new and old storm windows are largely in the quality of the weatherstripping surrounding the storm sash and the sash/frame fit, if frames for both are caulked to the exterior trim.

6c. Infiltrative versus Non-infiltrative Thermal Losses

Another factor to consider was the relative importance of infiltrative losses versus non-infiltrative losses. Whole window infiltrative thermal loss rates (L_{inf}) were compared to whole window non-infiltrative loss rates (L_u) for window upgrades to gain an understanding of their relative importance. Infiltrative loss rates averaged 16% of non-infiltrative loss rates with only two sites showing an infiltrative/non-infiltrative loss ratio greater than 18%, results supported by the literature (Klems, 1983).

The savings due to a reduction of non-infiltrative thermal loss rates realized by the use of double- versus single-glazed sash was investigated. Three original sash windows of varying leakage characteristics were chosen and annual costs modeled with both single- and double-glazing with a storm window in place. The loose window was based on the site 12 average heating season infiltration rate, the average window was based on the site 7 average, and the tight window was based on the site 19 average. Results were compared to those costs for assumed typical, tight, and loose windows and are shown in Table 21.

An additional benefit of double-glazed sash versus a single-glazing and storm window combination, arises from occupant behavior. During field testing, buildings were seen with a portion of storm windows open during the heating season, an obvious result of occupant behavior. Storm sash in the open position were effectively windows without storms, having greater thermal loss rates. The use of double-glazed sash would negate occupant behavior as no storm window is generally installed if the window is a replacement.

If a double-glazed sash were combined with a storm window (ie, triple-glazing), a larger portion of savings would arise from reduced non-infiltrative loss rates (U-values) due to the third glazing layer. Benefits of triple-glazing are somewhat reduced from what might be expected however, due to the gap distance between the prime and storm windows

Table 21: comparison of first year energy savings per window from double- versus single-glazed sash

Windows from Site:	Tighter Window		Average Window		Looser Window	
	Single-pane	Double-pane	Single-pane	Double-pane	Single-pane	Double-pane
13	***	***	***	***	$13.00	$13.50
7	$0.05	$0.50	$1.60	$2.10	$14.60	$15.10
19	$0.60	$1.10	$2.10	$2.60	$15.20	$15.60

(average 2.5 inches). A reduction in U-values occurs until the optimal gap distance of 0.75 inches is exceeded, after which point U-values exhibit a slow rise as gap distance increases. Triple-glazing was not investigated in this study but was shown to be effective in very cold climates (Flanders, 1982).

7.CONCLUSIONS

Over the course of the study, it became apparent that replacing an historic window does not necessarily result in greater energy savings than upgrading that same window. The decision to renovate or replace a window should not be based solely on energy considerations, as the differences in estimated first year savings between the upgrade options are small. Other factors to consider include life cycle costs, the historical significance of a window and its role in a building's character, occupant comfort, ease of operation, and life-cycle costing, none of which were subjects of this study.

The study addressed the following issues:

- estimate energy savings attributable to existing window retrofits,
- estimate first year savings in heating costs attributable to field tested window retrofits,
- estimate installation and materials costs for existing window retrofits, and
- compare the estimated costs and savings from existing window retrofits to those incurred by replacement windows.

Table 22 summarizes the results of the study by showing estimated purchase and installation costs for the various upgrades field tested as well as comparative savings to the assumed tight, typical, and loose windows. It should be noted again that savings are relative only to each other and do not reflect actual savings. This is due to the modified use of the LBL correlation model used in the study. The field tested window upgrades may be categorized into eight broad groups as follows:

1. retain the original sash using bronze (or plastic) V-strip weatherstripping;
2. retain the original sash utilizing vinyl jamb liners and silicone bulb weatherstripping;
3. retain the original sash by use of the Bi-Glass System upgrade;
5. retain the original sash utilizing new aluminum triple track storm windows;
5. retain the original sash utilizing interior storm windows;
6. single-glazed replacement sash utilizing vinyl jamb liners and silicone bulb weatherstripping;
7. double-glazed replacement sash utilizing vinyl jamb liners and silicone bulb weatherstripping; and
8. double-glazed replacement window insert.

Estimated installation and purchase costs are shown with and without costs associated with lead abatement. Lead abatement was assumed to cost $125. The purchase cost shown for single-glazed replacement sash with vinyl jamb liners is for in-kind replacement (two over two true divided lites). The other replacement sash are one over ones as encountered in the field.

It can be seen that bronze V-strip weatherstripping (category 1) compares favorably to the

Table 22: Estimated costs and first year energy savings of categorized upgrades

		Cost of window with lead abatement**:		First year energy savings per window as compared to assumed:		
	Upgrade category	excluded	included**	Tight window	Typical window	Loose window
Retain original sash	1	$76	$201	$0.60	$2.10	$15.20
	2	$175	$300	$0.05	$1.60	$14.60
	3	$225	$350	$0.80	$2.40	$15.40
	4	$70	$195	$1.00	$2.50	$15.50
	5	$115	$240	$1.30	$2.80	$15.90
Replacement sash	6	$214	---	$0.20	$1.70	$14.70
	7	$320	---	$0.70	$2.30	$15.30
	8	$500	---	$2.10	$3.60	$16.60

**Lead abatement cost assumed to be $125

other upgrade options while also being the least expensive option. However, due to the low sample population (two windows), no statistical significance may be associated with this observation. Bronze V-strip is visually unobtrusive as was noted several times during field research.

In-kind wood sash used as replacement sash can help retain the appearance of the building. Most windows tested during the study were two over twos, with in-kind replacements closely approximating the look of the original sash. One illustrative instance occurred when one face of a building containing six windows was being examined from the exterior. No difference was noted between any windows until inside, when two windows were discovered to be in-kind replacements.

Replacement window inserts may also retain the original appearance of a building while providing the additional benefit of reducing extraneous leakage, making the immediate window environment more comfortable for occupants. Actual window size is decreased when using window inserts due to the integral frame, modifying the building appearance somewhat.

The following points came to light during the course of the study.

- Exterior air infiltrating through the jamb from the rough opening had a significant contribution to the heat load of a window.
- Existing aluminum triple track or fixed panel aluminum storm windows reduced sash leakage by 45% on average.

- New aluminum triple track storm windows tested decreased sash leakage by 75% on average when the frame is caulked to the exterior trim.
- Interior storm windows significantly reduced both sash leakage and exterior air leakage, averaging reductions of approximately 95% and 80% respectively.
- A second glazing layer either from using a closed storm window or double-pane glass significantly reduced non-infiltrative losses.
- Pulley-type windows allowed significantly more exterior air leakage than pin-type windows.
- Original sash filled with vinyl jamb liners and silicone bulb weatherstripping show significantly reduced sash leakage rates over the original condition windows.
- In-kind replacement sash with vinyl jamb liners were effective when placed in a square jamb. Existing jambs utilizing this option should be checked for squareness.
- Replacement window inserts did not always reduce exterior air infiltration as expected, causing the window to perform poorly.
- Thermal performance of all options are subject to variation due to the quality of installation.

The study showed that window replacement will not necessarily reduce energy costs more than an upgrade utilizing the existing sash. The importance of the window frame/rough opening junction was noted throughout the study. An effective method of sealing this junction can greatly reduce the infiltrative thermal losses associated with any window renovation. Storm windows, either existing or replacements, were found to be effective in reducing both infiltrative and non-infiltrative losses. Many sash-retaining upgrades generally retain existing exterior storm windows, which may be left open by occupants. Consequently, options including double-glazed sash are likely to achieve more consistent energy savings than storm window options. Quantifying those differences was beyond the scope of this study.

Further research that would help quantify some of these issues include:

- validate and/or modify the method used to estimate the fraction of extraneous air leakage coming from the outside of the building;
- improve the sample size of the windows tested to achieve more statistically significant results;
- perform economic analyses of window upgrade options, including life cycle costing of installation, financing, maintenance and energy costs; and
- investigate triple-glazing and other upgrade strategies.

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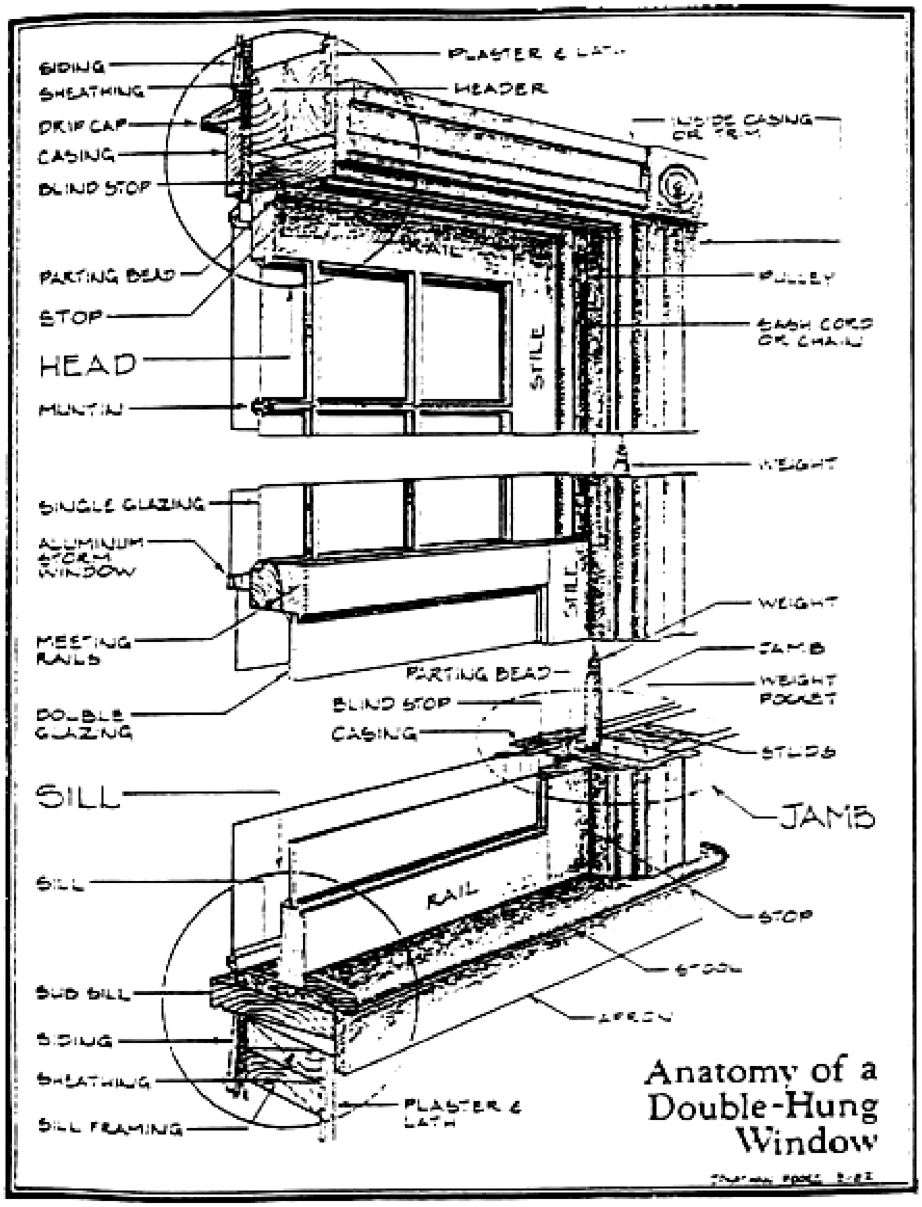
8. APPENDIX

8a.Anatomy of a Double-Hung Window



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8b. Flow and Regression Data for Field Tested Windows

8b i. Sash air leakage (Q_s)

Window ID	Storm Window Up or Off							Storm Window Down or On						
	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef
1 A		1.19	0.307	0.087	0.7109	0.9564	0.4607		0.92	0.196	0.056	0.5384	0.9404	0.5287
1B		2.91	0.519	0.147	1.7313	0.9642	0.5992		1.81	0.428	0.121	1.1723	0.9854	0.4961
1C		1.85	0.498	0.142	1.1103	0.9640	0.4394		1.17	0.286	0.081	0.7739	0.9585	0.5216
2A		3.51	0.496	0.141	2.0599	1.0000	0.6674		1.68	0.273	0.077	1.2654	0.9869	0.6201
2B		4.91	0.486	0.138	2.5401	0.9998	0.7887		1.09	0.184	0.053	0.8183	0.9162	0.6072
2C		3.41	0.551	0.156	1.9762	0.9997	0.6222		2.01	0.059	0.017	2.1494	0.9913	1.2039
2A2	0.38	0.39	0.089	0.026	-0.3466	0.8692	0.5002	0.18	0.27	0.044	0.013	-0.5850	0.7267	0.6136
2B2	0.25	0.25	0.056	0.016	-0.7631	0.7543	0.5118	0.06	0.09	0.051	0.014	-2.2793	0.1218	0.1694
2C2		0.80	0.244	0.070	0.2610	0.8794	0.4039	0.37	0.32	0.118	0.033	-0.7396	0.5091	0.3374
3A		2.13	0.350	0.099	1.4992	0.9939	0.6164							
3B		2.00	0.461	0.131	1.2938	0.9852	0.5003							
3C		1.22	0.246	0.070	0.8510	0.9708	0.5444		0.61	0.097	0.028	0.2630	0.8991	0.6276
3D		1.18	0.326	0.093	0.6966	0.8743	0.4397							
3E		0.98	0.138	0.039	0.7843	0.9856	0.6686							
3F		1.01	0.151	0.043	0.7893	0.9771	0.6493		0.60	0.091	0.026	0.2646	0.7466	0.6424
3G														
3H		3.22	0.477	0.136	1.9531	0.9267	0.6516		1.41	0.222	0.063	1.0991	0.9093	0.6298
3I		2.73	0.316	0.090	1.8895	0.9703	0.7353		1.65	0.367	0.104	1.1106	0.9710	0.5110
3A2														
3B2	0.45	0.43	0.127	0.037	-0.3479	0.8518	0.4144	0.40	0.40	0.157	0.044	-0.5546	0.7117	0.3140
3C2	0.12	0.09	0.077	0.022	-2.3620	0.0059	0.0483	0.23	0.16	0.049	0.014	-1.3150	0.3269	0.4082
3D2	0.11	0.10	0.034	0.010	-1.9017	0.5069	0.3576	0.11	0.10	0.034	0.010	-1.9017	0.5069	0.3576
3E2														
4A		2.36	0.151	0.043	1.9696	0.9698	0.9387		2.14	0.059	0.017	2.2310	0.9139	1.2222
4B														
4C		1.78	0.337	0.096	1.2569	0.9712	0.5673		1.33	0.084	0.024	1.4202	0.6843	0.9426
4D		0.95	0.201	0.057	0.5848	0.9167	0.5290		1.10	0.176	0.051	0.8384	0.8952	0.6226
4E									7.62	0.207	0.059	3.5123	1.0000	1.2306
5A								1.64	1.62	0.463	0.131	0.9979	0.9865	0.4279
5B	1.33	1.36	0.328	0.094	0.8879	0.9971	0.4840							
5C	0.56	0.67	0.164	0.046	0.1642	0.8873	0.4776	0.40	0.39	0.132	0.038	-0.5061	0.8806	0.3663
5D								0.06	0.05	0.019	0.005	-2.4498	0.6088	0.3548
5E														
5F								0.55	0.59	0.110	0.031	0.1643	0.9330	0.5751
5G		0.91	0.186	0.053	0.5586	0.9763	0.5419	0.00	0.80	0.133	0.038	0.5037	0.9856	0.6061
5H	0.49	0.47	0.111	0.031	-0.1554	0.9452	0.4954	0.45	0.37	0.122	0.034	-0.5431	0.7324	0.3775
6A **		5.94	1.35	0.38	2.3921	0.9994	0.5066							
6B **								0.62	0.51	0.25	0.07	-0.3890	0.4423	0.2437
6C **	1.76	1.76	0.40	0.11	1.1771	0.9456	0.5073							
6D **	1.14	1.29	0.17	0.05	1.0834	0.9032	0.6905							
6A2	0.05	0.05	0.004	0.001	-1.8141	0.9122	0.8550							
6B2	0.06	0.06	0.003	0.001	-1.5161	0.9170	0.9839							
6C2	0.16	0.23	0.003	0.001	0.2827	0.8786	1.4671							
6D2	0.15	0.15	0.016	0.004	-1.0032	0.9627	0.7601							
6E 2	0.36	0.26	0.034	0.010	-0.5375	0.9071	0.6867							
6F2	0.16	0.06	0.005	0.001	-1.7061	0.6208	0.8486							

Sash air leakage (Q_S) continued

Window	Storm Window Up or Off							Storm Window Down or On						
ID	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef
11 A	0.17	0.16	0.014	0.004	-0.7924	0.9208	0.8365							
11 B	0.02	0.04	0.011	0.003	-2.7665	0.3574	0.4252							
11 C	0.14	0.16	0.055	0.015	-1.3799	0.7569	0.3701							
11 D	0.13	0.11	0.085	0.024	-2.0996	0.1170	0.0896							
11 E	0.36	0.36	0.024	0.006	0.0931	0.9757	0.9332							
11 F	0.06	0.06	0.040	0.011	-2.5502	0.2263	0.1646							
12 A		1.98	0.769	0.218	1.0717	0.8445	0.3227		1.02	0.178	0.051	0.7444	0.9631	0.5982
12 B		0.30	0.082	0.023	-0.6426	0.4569	0.4519		0.28	0.065	0.018	-0.6626	0.6079	0.5014
12 C	0.37	0.33	0.100	0.029	-0.6003	0.9206	0.4106	0.37	0.31	0.094	0.027	-0.6876	0.9206	0.4106
12 D		0.15	0.037	0.011	-1.3264	0.8231	0.4781		0.13	0.044	0.013	-1.6486	0.2957	0.3579
12 E		0.76	0.297	0.085	0.1156	0.7724	0.3213		0.74	0.082	0.024	0.6035	0.9356	0.7523
12 F	0.34	0.44	0.017	0.005	0.4992	0.9082	1.1012	0.34	0.44	0.011	0.003	0.7483	0.8590	1.2813
12 G		3.00	0.390	0.111	1.9383	0.9955	0.6966		2.21	0.329	0.094	1.5730	0.9674	0.6490
12 H		2.10	0.585	0.167	1.2634	0.9895	0.4352		0.69	0.095	0.027	0.4481	0.8661	0.6784
12 I		2.53	0.703	0.200	1.4541	0.9996	0.4368		0.86	0.312	0.088	0.2745	0.8229	0.3482
12 J														
13 A		1.54	0.400	0.114	0.9678	0.9425	0.4606		0.58	0.176	0.051	-0.0669	0.7900	0.4027
13 B		1.22	0.490	0.138	0.5722	0.9390	0.3135		0.73	0.161	0.046	0.2988	0.7637	0.5131
13 C		1.83	0.557	0.158	1.0962	1.0000	0.4065		1.66	0.088	0.025	1.7111	1.0000	1.0000
13 D		1.25	0.480	0.137	0.6162	0.8372	0.3264		0.89	0.371	0.105	0.2424	0.5627	0.2981
13 E		1.82	0.563	0.160	1.0792	0.9757	0.4000		1.31	0.394	0.112	0.7619	0.9751	0.4095
13 F		0.67	0.291	0.083	-0.0646	0.3062	0.2830		0.45	0.112	0.031	-0.2312	0.9133	0.4744
13 G		1.08	0.317	0.090	0.5707	0.7640	0.4155		0.74	0.275	0.079	0.1120	0.5868	0.3385
13 H		1.78	0.211	0.060	1.4457	0.9932	0.7263		1.02	0.165	0.047	0.7654	0.9139	0.6206
13 I		1.08	0.354	0.101	0.5312	0.9130	0.3795		0.65	0.265	0.075	-0.0765	0.7344	0.3032
13 J	0.28	0.26	0.067	0.019	-0.7803	0.8136	0.4674	0.23	0.17	0.027	0.008	-0.9569	0.7436	0.6455
14 A	0.79	0.84	0.166	0.047	0.4830	0.8934	0.5512	0.17	0.26	0.002	0.001	0.6116	0.7771	1.6306
14 B		1.74	0.553	0.157	1.0297	0.8668	0.3922	0.28	0.25	0.053	0.015	-0.7808	0.8531	0.5243
14 C		1.37	0.321	0.091	0.9064	0.9885	0.4939	0.33	0.37	0.077	0.022	-0.3488	0.8197	0.5344
14 D	0.56	0.67	0.099	0.028	0.3812	0.8838	0.6507	0.17	0.18	0.018	0.005	-0.7721	0.8936	0.7878
14 E	1.12	1.04	0.542	0.154	0.3167	0.9600	0.2244	0.03	0.06	0.062	0.017	-2.6487	0.0010	0.0304
14 F		1.18	0.492	0.140	0.5286	0.9889	0.2994	0.02	0.02	0.077	0.022	-4.4737	0.6440	-0.4630
15 A 1									2.11	0.113	0.032	1.9513	1.0000	1.0000
15 A 2														
15 B 1		2.16	0.330	0.094	1.5449	0.9856	0.6412		0.36	0.351	0.100	-1.0483		0.0000
15 B 2								0.01	0.01	0.008	0.002	-4.9564	1.0000	-0.0000
15 C 1														
15 C 2														
15 D 1								0.70	0.25	0.070	0.007	1.0733	0.3569	0.0300
15 D 2														
16 A								0.00	0.52	0.213	0.060	-0.3007	1.0000	0.3018
16 B								0.00	0.01	0.597	0.170	-6.1266	1.0000	-1.3569
16 C														
16 D														
16 E														
16 F					0.0733									
16 G		0.55	0.054	0.015	0.3624	1.0000	0.7937							
17 A	0.09	0.09	0.087	0.025	-2.4419		0.0000	0.09	0.09	0.087	0.025	-2.4419		0.0000
17 B	0.17	0.20	0.045	0.013	-0.9981	0.5887	0.5104	0.09	0.12	0.029	0.009	-1.5635	0.7429	0.4752
17 C	0.26	0.24	0.132	0.038	-1.2320	0.2568	0.1920	0.09	0.13	0.049	0.014	-1.6114	0.4717	0.3356
18 A	0.33	0.32	0.026	0.008	-0.1134	0.9835	0.8571							
18 B	0.11	0.09	0.014	0.004	-1.6243	0.9208	0.6412							
19 A	0.39	0.41	0.090	0.026	-0.2587	0.8700	0.5183	0.28	0.30	0.070	0.020	-0.6209	0.7986	0.4923
19 B	0.49	0.57	0.109	0.031	0.1214	0.8937	0.5653	0.33	0.40	0.088	0.025	-0.2964	0.8843	0.5154

Sash air leakage (Q_s) continued

Window ID	Storm Window Up or Off							Storm Window Down or On						
	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef
7A		0.95	0.061	0.017	1.0780	0.9539	0.9377		0.97	0.008	0.002	1.9446	0.6459	0.6464
7B		0.88	0.609	0.173	0.0189	0.2920	0.1247							
7C									4.40	0.112	0.032	2.9678	0.9771	1.2518
7D		0.80	0.204	0.058	0.3307	0.9360	0.4641							
7E		1.92	0.572	0.162	1.1494	0.9748	0.4131							
7F		1.26	0.509	0.144	0.6059	0.9055	0.3101							
7G														
7H		2.14	0.484	0.138	1.3706	0.9895	0.5066							
7I		1.00	0.218	0.062	0.6292	0.9793	0.5205		0.70	0.144	0.041	0.2920	0.7430	0.5390
7J		0.20	0.333	0.095	-1.8151	0.1921	-0.1730							
7K		4.06	0.636	0.181	2.1690	1.0000	0.6339							
7L														
7 A 2		0.48	0.111	0.031	-0.1066	0.9792	0.5057							
7 B 2		2.00	0.315	0.089	1.4499	0.8666	0.6295		1.32	0.226	0.065	1.0029	0.8662	0.6025
7 C 2	0.43	0.47	0.129	0.037	-0.2156	0.8030	0.4437							
7 D 2		1.61	0.386	0.110	1.0683	0.9986	0.4882							
7 E 2	0.24	0.27	0.023	0.006	-0.3014	0.8412	0.8414							
7 F 2		1.25	0.374	0.107	0.7126	0.9904	0.4102							
7 G 2	0.19	0.19	0.054	0.015	-1.1503	0.8176	0.4291							
7 H 2	0.51	0.57	0.076	0.022	0.2645	0.7120	0.6855							
7 I 2	0.77	0.75	0.145	0.042	0.3957	0.9191	0.5614							
7 J 2	1.07	1.09	0.220	0.062	0.7416	0.9282	0.5454							
7 K 2	0.80	0.85	0.127	0.037	0.6176	0.9425	0.6476							
7 L 2	1.07	1.11	0.152	0.043	0.9246	0.9497	0.6790							
7 M 2	0.90	0.93	0.245	0.070	0.4724	0.9274	0.4536							
7 N 2	0.58	0.56	0.101	0.029	0.1255	0.8453	0.5853							
7 O 2		0.62	0.128	0.037	0.1753	0.8720	0.5387							
7 P 2	1.04	1.04	0.221	0.062	0.6765	0.9758	0.5289							
7 Q 2		0.22	0.109	0.031	-1.2552	0.2597	0.2339							
7 R 2	0.42	0.38	0.081	0.023	-0.3540	0.8162	0.5219							
7 S 2		0.36	0.069	0.019	-0.3556	0.9570	0.5606							
7 T 2	0.05	0.05	0.003	0.001	-1.6521	0.5294	1.0120							
8A		1.75	0.492	0.140	1.0800	0.9917	0.4327							
8B		2.12	0.338	0.096	1.5056	0.7825	0.6268							
8C		3.63	0.861	0.244	1.8786	0.9985	0.4906							
8D								0.05	0.06	0.017	0.004	-2.1401	0.4307	0.4720
8E								0.17	0.17	0.024	0.006	-0.9557	0.5629	0.6788
8F								0.05	0.05	0.056	0.016	-2.8883		
9A		2.38	0.521	0.148	1.4921	0.9827	0.5186		1.46	0.222	0.063	1.1571	0.9889	0.6450
9B		1.98	0.376	0.107	1.3639	0.9905	0.5665		1.59	0.247	0.070	1.2313	0.9818	0.6353
9C		2.80	0.845	0.240	1.5217	1.0000	0.4088							
9D		1.09	0.281	0.080	0.6434	0.9587	0.4630		0.83	0.310	0.088	0.2142	0.9429	0.3350
9E	0.52	0.54	0.097	0.028	0.0764	0.9337	0.5819							
9F		2.46	0.824	0.235	1.3540	1.0000	0.3740		1.47	0.072	0.020	1.6216	0.7085	1.0238
10A1	1.03	1.10	0.751	0.213	0.2514	0.8373	0.1300							
10A2								0.05	0.05	0.046	0.013	-2.7265	0.3078	0.0863
10B1	1.82	1.80	0.833	0.237	0.8994	0.9916	0.2619							
10B2								0.84	0.93	0.111	0.031	0.7920	0.9610	0.7228
10C1	1.03	1.10	0.748	0.213	0.2475	0.8373	0.1300							
10C2								0.46	0.48	0.122	0.034	-0.1442	0.9127	0.4754
10D 1		2.64	0.457	0.130	1.6903	1.0000	0.5978		1.62	0.194	0.055	1.3582	0.9390	0.7253
10D 2	0.10	0.10	0.054	0.015	-2.0768	0.1632	0.2052	0.19	0.18	0.071	0.020	-1.3101	0.4986	0.3232

8b ii. Extraneous air leakage (Qe)

	Storm Window Up or Off							Storm Window Down or On						
	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef
1 A		1.27	0.159	0.046	1.0857	0.9821	0.7080		1.25	0.168	0.048	1.0517	0.9913	0.6882
1B		0.66	0.072	0.020	0.4890	0.9926	0.7609		0.67	0.176	0.021	0.5036	0.9898	0.7621
1C		1.15	0.130	0.076	1.0195	0.9930	0.7412		1.18	0.136	0.039	1.0484	0.9915	0.7424
2A		1.97	0.306	0.087	1.4430	0.9972	0.6360		2.00	0.352	0.100	1.4077	0.9978	0.5928
2B		2.13	0.330	0.094	1.5188	0.9835	0.6353		2.15	0.322	0.091	1.5497	0.9869	0.6486
2C		2.46	0.424	0.121	1.6231	0.9970	0.6003		2.54	0.441	0.126	1.6494	0.9945	0.5966
2A2	1.37	1.33	0.152	0.043	1.1841	0.9966	0.7429	1.37	1.33	0.151	0.043	1.1893	0.9966	0.7457
2B2	1.72	1.74	0.244	0.069	1.3629	0.9963	0.6706	1.72	1.76	0.241	0.069	1.3881	0.9940	0.6797
2C2	1.90	2.03	0.209	0.059	1.6434	0.9818	0.7768	1.90	2.02	0.212	0.060	1.6305	0.9833	0.7690
3A		2.71	0.406	0.115	1.7755	0.9649	0.6477							
3B	1.52	1.71	0.111	0.031	1.6620	0.9808	0.9336							
3C	1.78	1.79	0.289	0.082	1.3251	0.9980	0.6205	1.83	1.85	0.329	0.094	1.3273	0.9962	0.5900
3D		2.81	0.550	0.156	1.7023	0.9976	0.5564							
3E	1.93	1.93	0.355	0.101	1.3516	0.9978	0.5769							
3F	2.15	2.13	0.577	0.164	1.2923	0.9978	0.4455	2.15	2.12	0.526	0.150	1.3270	0.9961	0.4763
3G	1.55	1.59	0.197	0.056	1.3211	0.9937	0.7121							
3H		3.03	0.463	0.131	1.8839	0.9948	0.6420		3.03	0.463	0.131	1.8839	0.9948	0.6420
3I		3.64	0.624	0.178	2.0168	0.9965	0.6018		3.52	0.590	0.168	1.9937	0.9985	0.6098
3A2	1.15	1.19	0.136	0.039	1.0782	0.9975	0.7445	1.15	1.21	0.135	0.038	1.0827	0.9977	0.7476
3B2	1.02	1.10	0.127	0.036	0.9812	0.9957	0.7374	1.02	1.10	0.131	0.038	0.9659	0.9961	0.7247
3C2	1.19	1.31	0.151	0.043	1.1861	0.9892	0.7395	1.19	1.32	0.148	0.042	1.1736	0.9866	0.7447
3D2	1.27	1.31	0.182	0.052	1.0832	0.9969	0.6746	1.27	1.31	0.185	0.053	1.0723	0.9972	0.6679
3E2														
4A	1.88	1.85	0.480	0.137	1.1725	0.9973	0.4612	1.88	1.81	0.493	0.140	1.1237	0.9818	0.4429
4B		3.76	0.767	0.218	1.9734	0.9759	0.5412		4.11	0.723	0.206	2.1286	0.9978	0.5931
4C	2.45	2.40	0.386	0.110	1.6288	0.9966	0.6240	2.52	2.44	0.392	0.111	1.6473	0.9956	0.6251
4D		3.13	0.415	0.118	1.9716	0.9939	0.6892		3.07	0.463	0.131	1.8974	0.9923	0.6450
4E		3.87	0.807	0.229	1.9968	0.9688	0.5347		4.18	0.756	0.215	2.1302	0.9877	0.5827
5A								0.44	0.43	0.061	0.017	-0.0460	0.9922	0.6629
5B	0.52	0.53	0.081	0.023	0.1207	0.9987	0.6378							
5C	0.84	0.84	0.140	0.040	0.5679	0.9878	0.6121	0.96	1.00	0.141	0.040	0.8121	0.9954	0.6701
5D								0.23	0.24	0.036	0.010	-0.6697	0.9986	0.6486
5E								0.09	0.09	0.016	0.004	-1.8554	0.9625	0.5433
5F								1.15	1.16	0.179	0.051	0.9223	0.9937	0.6389
5G	1.89	1.86	0.330	0.094	1.3292	0.9963	0.5890	1.85	1.83	0.334	0.095	1.3010	0.9962	0.5798
5H	1.55	1.56	0.224	0.063	1.2464	0.9975	0.6629	1.50	1.58	0.197	0.056	1.3139	0.9912	0.7110
6A **		3.96	0.60	0.17	2.1473	0.9985	0.6410							
6B **								2.83	3.13	0.27	0.08	2.1537	0.9780	0.8413
6C **	2.50	2.56	0.30	0.09	1.8165	0.9951	0.7292							
6D **	2.39	2.49	0.23	0.07	1.8792	0.9976	0.8049							
6A2	0.84	0.87	0.105	0.030	0.7256	0.9942	0.7194							
6B2	0.29	0.29	0.030	0.009	-0.3188	0.9856	0.7683							
6C2	0.34	0.34	0.054	0.015	-0.3061	0.9943	0.6345							
6D2	0.33	0.33	0.041	0.012	-0.2502	0.9803	0.7103							
6E 2	0.33	0.32	0.046	0.013	-0.3236	0.9927	0.6652							
6F2	0.52	0.51	0.091	0.026	0.0122	0.9560	0.5805							

Extraneous air leakage (Q_e) continued

	Storm Window Up or Off							Storm Window Down or On						
	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef
7A	1.69	1.67	0.265	0.075	1.2717	0.9899	0.6294	1.69	1.67	0.293	0.083	1.2226	0.9945	0.5929
7B		2.21	0.396	0.113	1.4961	0.9825	0.5863							
7C									1.67	0.298	0.085	1.2221	0.9848	0.5885
7D		3.01	0.513	0.146	1.8274	0.9894	0.6033							
7E	1.58	1.61	0.253	0.072	1.2426	0.9976	0.6325							
7F	1.78	1.84	0.244	0.070	1.4403	0.9923	0.6891							
7G		2.12	0.414	0.117	1.4224	0.9965	0.5574							
7H	1.83	1.85	0.298	0.085	1.3690	0.9940	0.6234							
7I		2.18	0.383	0.109	1.4972	0.9943	0.5940		2.29	0.392	0.112	1.5526	0.9900	0.6019
7J		3.48	0.577	0.164	1.9832	0.9901	0.6127							
7K	1.58	1.61	0.238	0.068	1.2683	0.9868	0.6535							
7L	1.38	1.40	0.161	0.046	1.2255	0.9923	0.7375							
7 A 2	1.53	1.59	0.200	0.057	1.3163	0.9920	0.7067							
7 B 2		2.26	0.312	0.089	1.6265	0.9953	0.6746		2.26	0.312	0.089	1.6265	0.9953	0.6746
7 C 2	0.85	0.85	0.057	0.016	0.9516	0.9978	0.9249							
7 D 2	0.46	0.46	0.042	0.012	0.2270	0.9953	0.8216							
7 E 2	1.42	1.46	0.222	0.063	1.1556	0.9919	0.6433							
7 F 2	0.95	0.99	0.108	0.031	0.9065	0.9880	0.7574							
7 G 2	0.90	0.95	0.072	0.020	1.0035	0.9935	0.8797							
7 H 2	1.02	1.04	0.112	0.031	0.9632	0.9869	0.7635							
7 I 2	1.08	1.10	0.135	0.039	0.9511	0.9834	0.7142							
7 J 2	0.97	1.00	0.124	0.036	0.8600	0.9904	0.7136							
7 K 2	1.07	1.10	0.118	0.033	1.0024	0.9965	0.7579							
7 L 2	0.90	0.93	0.121	0.034	0.7547	0.9926	0.6939							
7 M 2	1.05	1.08	0.136	0.039	0.9248	0.9987	0.7077							
7 N 2	1.26	0.00	0.173	0.049	1.1022	0.9930	0.6903							
7 O 2	1.62	1.69	0.212	0.060	1.3774	0.9857	0.7082							
7 P 2	1.04	1.05	0.119	0.033	0.9556	0.9963	0.7457							
7 Q 2	2.09	2.12	0.324	0.093	1.5198	0.9940	0.6403							
7 R 2	1.19	1.28	0.156	0.044	1.1153	0.9900	0.7191							
7 S 2	1.61	1.66	0.250	0.071	1.2798	0.9904	0.6455							
7 T 2	0.75	0.73	0.073	0.020	0.6358	0.9980	0.7871							
8A	1.46	1.51	0.230	0.066	1.1803	0.9975	0.6401							
8B	2.06	2.04	0.336	0.096	1.4600	0.9942	0.6168							
8C	1.35	1.40	0.198	0.056	1.1435	0.9972	0.6688							
8D								1.33	1.40	0.168	0.047	1.2031	0.9939	0.7221
8E								1.61	1.65	0.179	0.051	1.4105	0.9941	0.7577
8F								1.39	1.45	0.199	0.057	1.1859	0.9951	0.6771
9A	0.57	0.56	0.054	0.015	0.3886	0.9978	0.8007	0.62	0.62	0.042	0.012	0.6301	0.9828	0.9176
9B	0.94	1.01	0.087	0.025	1.0106	0.9957	0.8330	1.09	1.14	0.091	0.026	1.1760	0.9916	0.8641
9C		2.23	0.305	0.086	1.6215	0.9961	0.6800							
9D	1.67	1.72	0.236	0.067	1.3639	0.9930	0.6798	1.71	1.76	0.241	0.069	1.3863	0.9890	0.6795
9E	1.30	1.37	0.158	0.045	1.1993	0.9884	0.7354							
9F		2.72	0.473	0.135	1.7215	0.9940	0.5972		2.72	0.473	0.135	1.7215	0.9940	0.5972
10A1	0.81	0.77	0.125	0.036	0.4836	0.9960	0.6194							
10A2								0.36	0.33	0.087	0.025	-0.5333	0.9920	0.4622
10B1	0.19	0.18	0.031	0.009	-0.9695	0.9872	0.6029							
10B2								0.19	0.18	0.031	0.009	-0.9747	0.9743	0.6046
10C1	0.80	0.76	0.125	0.036	0.4797	0.9960	0.6194							
10C2								0.86	0.85	0.133	0.038	0.5954	0.9960	0.6302
10D 1		2.26	0.466	0.132	1.4655	0.9960	0.5388	0.00	2.25	0.396	0.113	1.5237	0.9961	0.5925
10D 2	1.54	1.55	0.260	0.074	1.1731	0.9974	0.6095	1.54	1.55	0.260	0.074	1.1731	0.9974	0.6095

Extraneous air leakage (Q_e) continued

	Storm Window Up or Off							Storm Window Down or On						
	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef
11 A	0.48	0.52	0.044	0.013	0.3375	0.9872	0.8341							
11 B	0.41	0.41	0.061	0.017	-0.1188	0.9989	0.6472							
11 C	0.28	0.28	0.037	0.011	-0.4389	0.9846	0.6957							
11 D	0.42	0.45	0.043	0.012	0.1822	0.9855	0.8040							
11 E	0.54	0.54	0.075	0.022	0.1809	0.9980	0.6698							
11 F	0.33	0.33	0.038	0.011	-0.2132	0.9957	0.7388							
12 A	2.26	2.27	0.362	0.103	1.5757	0.9913	0.6269	2.26	2.30	0.373	0.107	1.5832	0.9943	0.6213
12 B	2.32	2.32	0.315	0.089	1.6806	0.9961	0.6853	2.32	2.34	0.314	0.089	1.6736	0.9976	0.6846
12 C	1.75	1.82	0.192	0.055	1.5231	0.9965	0.7684	1.75	1.82	0.192	0.055	1.5206	0.9966	0.7671
12 D	2.26	2.39	0.242	0.069	1.8093	0.9924	0.7806	2.26	2.38	0.243	0.069	1.8039	0.9932	0.7777
12 E		2.56	0.282	0.080	1.8482	0.9898	0.7534		2.55	0.284	0.081	1.8394	0.9910	0.7487
12 F	1.27	1.33	0.117	0.033	1.2903	0.9966	0.8298	1.27	1.33	0.117	0.033	1.2903	0.9966	0.8298
12 G	1.27	1.37	0.136	0.039	1.2571	0.9925	0.7877	1.27	1.36	0.137	0.039	1.2521	0.9917	0.7850
12 H	2.20	2.26	0.322	0.091	1.6156	0.9914	0.6651	2.20	2.26	0.322	0.091	1.6156	0.9914	0.6651
12 I		2.49	0.311	0.088	1.7670	0.9978	0.7097		2.49	0.311	0.088	1.7670	0.9978	0.7097
12 J		5.65	0.905	0.257	2.4850	0.9993	0.6251		5.65	0.905	0.257	2.4850	0.9993	0.6251
13 A	1.98	2.00	0.337	0.096	1.4234	0.9914	0.6072	1.98	2.00	0.337	0.096	1.4234	0.9914	0.6072
13 B	1.90	1.97	0.242	0.069	1.5404	0.9890	0.7152	1.90	1.97	0.242	0.069	1.5404	0.9890	0.7152
13 C		3.48	0.659	0.187	1.9308	0.9977	0.5678		3.48	0.659	0.187	1.9308	0.9977	0.5678
13 D		2.18	0.302	0.086	1.5903	0.9918	0.6738		2.18	0.302	0.086	1.5903	0.9918	0.6738
13 E	1.22	1.32	0.121	0.034	1.2637	0.9925	0.8176		1.32	0.121	0.034	1.2637	0.9925	0.8176
13 F		2.46	0.428	0.122	1.6216	0.9936	0.5974		2.46	0.428	0.122	1.6216	0.9936	0.5974
13 G	2.17	2.23	0.328	0.094	1.5899	0.9900	0.6539		2.23	0.328	0.094	1.5899	0.9900	0.6539
13 H		2.44	0.341	0.097	1.7049	0.9989	0.6728		2.44	0.341	0.097	1.7049	0.9989	0.6728
13 I		2.29	0.348	0.099	1.6066	0.9936	0.6442		2.29	0.348	0.099	1.6066	0.9936	0.6442
13 J	1.76	1.89	0.208	0.059	1.5433	0.9790	0.7534		1.89	0.208	0.059	1.5433	0.9790	0.7534
14 A	0.96	0.99	0.102	0.029	0.9216	0.9935	0.7749	0.96	0.99	0.102	0.029	0.9216	0.9935	0.7749
14 B	1.41	1.48	0.202	0.057	1.2116	0.9901	0.6794	1.41	1.48	0.202	0.057	1.2116	0.9901	0.6794
14 C	1.35	1.39	0.140	0.040	1.2706	0.9974	0.7828	1.35	1.39	0.140	0.040	1.2706	0.9974	0.7828
14 D	0.85	0.82	0.099	0.028	0.6612	0.9950	0.7200	0.85	0.82	0.099	0.028	0.6612	0.9950	0.7200
14 E	1.12	1.16	0.126	0.036	1.0674	0.9968	0.7601	0.54	0.51	0.081	0.023	0.0583	0.9831	0.6226
14 F	1.05	1.09	0.089	0.026	1.1159	0.9954	0.8539	0.40	0.41	0.069	0.019	-0.1803	0.9960	0.6018
15 A 1		4.98	1.117	0.317	2.2213	0.9969	0.5104		4.98	1.117	0.317	2.2213	0.9969	0.5104
15 A 2								0.31	0.32	0.135	0.039	-0.7846	0.9833	0.2954
15 B 1		3.84	0.712	0.202	2.0399	0.9931	0.5754		3.84	0.712	0.202	2.0399	0.9931	0.5754
15 B 2								0.34	0.36	0.145	0.041	-0.6823	0.9693	0.3017
15 C 1		5.44	1.228	0.349	2.3056	1.0000	0.5080		4.98	1.117	0.317	2.2213	0.9969	0.5104
15 C 2								0.42	0.41	0.245	0.070	-0.6771	0.9787	0.1756
15 D 1		5.22	1.059	0.301	2.3074	0.9993	0.5440		3.84	0.712	0.202	2.0399	0.9931	0.5754
15 D 2								0.26	0.26	0.085	0.025	-0.8961	0.9916	0.3785
16 A		4.45	0.616	0.175	2.3079	1.0000	0.6753		4.45	0.616	0.175	2.3079	1.0000	0.6753
16 B		4.19	0.804	0.228	2.1103	1.0000	0.5632		4.19	0.804	0.228	2.1103	1.0000	0.5632
16 C		4.15	0.839	0.239	2.0813	1.0000	0.5456		4.15	0.839	0.239	2.0813	1.0000	0.5456
16 D		4.14	0.795	0.226	2.0991	1.0000	0.5632		4.14	0.795	0.226	2.0991	1.0000	0.5632
16 E		6.41	0.918	0.260	2.6574	0.9980	0.6634							
16 F		4.56	0.915	0.260	2.1769	0.9998	0.5479							
16 G		4.53	0.636	0.181	2.3176	0.9951	0.6701							
17 A	2.35	2.37	0.409	0.116	1.5843	0.9930	0.5995	2.35	2.37	0.409	0.116	1.5843	0.9930	0.5995
17 B	1.90	1.98	0.268	0.076	1.5061	0.9969	0.6827	1.90	1.98	0.268	0.076	1.5061	0.9969	0.6827
17 C	2.40	2.44	0.441	0.126	1.5932	0.9920	0.5833	2.40	2.44	0.441	0.126	1.5932	0.9920	0.5833
18 A	0.54	0.53	0.071	0.020	0.1907	0.9963	0.6860							
18 B	0.58	0.55	0.086	0.025	0.1766	0.9914	0.6372							
19 A	1.27	1.31	0.155	0.044	1.1506	0.9911	0.7288	1.27	1.31	0.155	0.044	1.1506	0.9911	0.7288
19 B	0.77	0.73	0.055	0.016	0.7535	0.9936	0.8835	0.77	0.73	0.055	0.016	0.7535	0.9936	0.8835

8b iii. Total air leakage (Q_t)

	Storm Window Up or Off							Storm Window Down or On						
	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef
1 A		2.47	0.455	0.129	1.5937	0.9948	0.5765		2.17	0.359	0.102	1.5100	0.9950	0.6140
1B		3.51	0.569	0.162	1.9677	0.9930	0.6259		2.40	0.473	0.135	1.5370	0.9936	0.5574
1C		2.89	0.714	0.203	1.6442	0.8773	0.4899		2.34	0.406	0.116	1.5732	0.9917	0.6051
2A		4.94	0.935	0.266	2.2805	0.9830	0.5678		3.68	0.624	0.178	2.0328	0.9993	0.6054
2B		6.83	0.822	0.234	2.7923	0.9913	0.7226		3.34	0.499	0.142	1.9856	0.9970	0.6482
2C		5.96	0.968	0.275	2.5319	0.9961	0.6201		4.24	0.475	0.135	2.3438	0.9995	0.7471
2A2	1.73	1.72	0.238	0.068	1.3551	0.9915	0.6752	1.55	1.62	0.193	0.055	1.3581	0.9894	0.7262
2B2	1.97	2.00	0.300	0.085	1.4715	0.9960	0.6468	1.79	1.82	0.281	0.080	1.3618	0.9956	0.6364
2C2		2.83	0.437	0.124	1.8056	0.9969	0.6371	2.27	2.30	0.327	0.093	1.6376	0.9935	0.6662
3A		4.98	0.744	0.211	2.3867	0.9698	0.6488							
3B		3.96	0.522	0.148	2.2082	0.9979	0.6913							
3C		3.00	0.534	0.152	1.8101	0.9933	0.5898		2.50	0.421	0.119	1.6438	0.9969	0.6066
3D		3.80	0.897	0.255	0.2589	0.9884	0.4925							
3E		2.87	0.498	0.142	1.7763	0.9954	0.5979							
3F		3.09	0.727	0.207	1.7228	0.9981	0.4937		2.71	0.622	0.176	1.6040	0.9939	0.5027
3G														
3H		6.39	0.931	0.265	2.6454	0.9836	0.6571		4.45	0.684	0.195	2.2616	0.9909	0.6385
3I		6.17	0.953	0.271	2.5861	0.9983	0.6370		5.12	0.957	0.272	2.3220	0.9999	0.5722
3A2	1.15	1.19	0.137	0.039	1.0696	0.9977	0.7400	1.15	1.19	0.135	0.039	1.0787	0.9971	0.7462
3B2	1.48	1.52	0.245	0.070	1.1675	0.9876	0.6220	1.42	1.48	0.271	0.077	1.0938	0.9869	0.5803
3C2	1.31	1.40	0.212	0.060	1.1119	0.9803	0.6439	1.42	1.47	0.203	0.058	1.2054	0.9873	0.6762
3D2	1.39	1.41	0.213	0.060	1.1192	0.9952	0.6446	1.39	1.41	0.216	0.061	1.1099	0.9952	0.6388
3E2	1.60	1.67	0.251	0.071	1.2935	0.9929	0.6472							
4A		3.80	0.624	0.178	2.0760	0.9914	0.6162		3.25	0.535	0.152	1.9207	0.9592	0.6160
4B														
4C		3.95	0.748	0.213	2.0578	0.9977	0.5678		3.53	0.514	0.146	2.0514	0.9852	0.6586
4D		4.19	0.604	0.172	2.2274	0.9910	0.6605		4.18	0.639	0.182	2.1995	0.9989	0.6400
4E									7.82	1.012	0.287	2.8984	1.0000	0.6982
5A								2.08	2.04	0.520	0.147	1.2777	0.9938	0.4672
5B	1.85	1.88	0.407	0.115	1.2592	0.9989	0.5221							
5C	1.40	1.52	0.301	0.085	1.0802	0.9824	0.5517	1.35	1.39	0.266	0.075	1.0062	0.9949	0.5638
5D								0.30	0.29	0.057	0.016	-0.5878	0.9907	0.5518
5E								0.09	0.09	0.016	0.004	-1.8554	0.9525	0.5433
5F								1.71	1.75	0.289	0.082	1.3050	0.9924	0.6157
5G		2.70	0.527	0.150	1.6625	0.9996	0.5568		2.60	0.471	0.133	1.6605	0.9976	0.5837
5H	2.04	2.03	0.335	0.095	1.4487	0.9982	0.6152	1.95	1.92	0.321	0.091	1.3861	0.9958	0.6106
6A **		10.09	1.91	0.54	2.9948	0.9996	0.5673							
6B **								3.46	3.53	0.48	0.14	2.0770	0.9895	0.6777
6C **	4.26	4.30	0.69	0.20	2.2128	0.9931	0.6250							
6D **	3.53	3.78	0.40	0.12	2.2458	0.9821	0.7619							
6A2	0.89	0.93	0.110	0.031	0.8002	0.9944	0.7268							
6B2	0.36	0.36	0.033	0.010	-0.0663	0.9946	0.8026							
6C2	0.51	0.53	0.055	0.015	0.3022	0.9920	0.7755							
6D2	0.48	0.47	0.057	0.016	0.1319	0.9898	0.7227							
6E 2	0.69	0.58	0.081	0.023	0.2759	0.9759	0.6765							
6F2	0.69	0.58	0.096	0.027	0.1985	0.9550	0.6151							

Total air leakage (Q_t) continued

	Storm Window Up or Off							Storm Window Down or On						
	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef
7A		2.59	0.320	0.090	1.6163	0.9810	0.7154		2.22	0.323	0.091	1.5896	0.9933	0.6582
7B		3.05	0.949	0.270	1.5920	0.9852	0.3976							
7C									4.80	0.411	0.117	2.5778	0.9887	0.8386
7D		3.86	0.710	0.202	2.0473	0.9977	0.5779							
7E		3.54	0.807	0.229	1.8735	0.9900	0.5048							
7F		3.17	0.706	0.201	1.7706	0.9992	0.5122							
7G														
7H		4.19	0.758	0.215	2.1344	0.9991	0.5833							
7I		3.19	0.599	0.170	1.8463	0.9933	0.5703		2.98	0.541	0.154	1.7945	0.9946	0.5822
7J		3.68	0.812	0.231	1.9223	0.9952	0.5151							
7K		5.15	0.893	0.254	2.3594	1.0000	0.5978							
7L														
7 A 2		2.10	0.307	0.087	1.5335	0.9979	0.6568							
7 B 2		4.27	0.627	0.179	2.2395	0.9942	0.6545		3.65	0.533	0.152	2.0835	0.9968	0.6559
7 C 2	1.28	1.32	0.161	0.046	1.1449	0.9897	0.7176							
7 D 2		2.09	0.413	0.117	1.4038	0.9978	0.5533							
7 E 2	1.67	1.72	0.247	0.070	1.3420	0.9854	0.6621							
7 F 2		2.25	0.462	0.131	1.4600	0.9942	0.5402							
7 G 2	1.09	1.15	0.107	0.030	1.1236	0.9938	0.8145							
7 H 2	1.53	1.61	0.199	0.056	1.3368	0.9727	0.7142							
7 I 2	1.85	1.86	0.279	0.080	1.3975	0.9914	0.6466							
7 J 2	2.03	2.09	0.342	0.097	1.4808	0.9873	0.6177							
7 K 2	1.87	1.95	0.245	0.070	1.5169	0.9912	0.7063							
7 L 2	1.97	2.03	0.274	0.077	1.5369	0.9877	0.6847							
7 M 2	1.96	2.00	0.372	0.107	1.3819	0.9863	0.5728							
7 N 2	1.84	1.88	0.275	0.079	1.4178	0.9930	0.6543							
7 O 2		2.32	0.340	0.097	1.6349	0.9991	0.6560							
7 P 2	2.09	2.10	0.335	0.095	1.4919	0.9925	0.6254							
7 Q 2		2.29	0.434	0.124	1.5162	0.9991	0.5688							
7 R 2	1.61	1.66	0.237	0.068	1.3045	0.9912	0.6636							
7 S 2		2.03	0.316	0.090	1.4718	0.9949	0.6345							
7 T 2	0.81	0.81	0.075	0.022	0.7610	0.9924	0.8098							
8A		3.26	0.710	0.202	1.8063	0.9943	0.5194							
8B		4.78	0.601	0.179	2.3976	0.9606	0.6924							
8C		4.94	1.056	0.300	2.2308	0.9994	0.5265							
8D								1.39	1.46	0.186	0.053	1.2262	0.9911	0.7030
8E								1.79	1.85	0.189	0.054	1.5518	0.9907	0.7772
8F								1.45	1.48	0.195	0.056	1.2307	0.9961	0.6929
9A		2.91	0.572	0.162	1.7314	0.9910	0.5538		2.08	0.260	0.074	1.5819	0.9908	0.7081
9B		2.95	0.457	0.130	1.8474	0.9955	0.6360		2.79	0.328	0.094	1.9034	0.9960	0.7301
9C		5.07	1.124	0.320	2.2412	1.0000	0.5136							
9D		2.92	0.495	0.141	1.7980	0.9997	0.6047		2.71	0.513	0.146	1.6825	0.9996	0.5682
9E	1.82	1.90	0.255	0.072	1.4689	0.9869	0.6857							
9F		4.28	1.377	0.392	1.9217	1.0000	0.3873		3.86	0.558	0.159	2.1457	0.9826	0.6597
10A1	1.84	1.85	0.820	0.234	0.9481	0.9935	0.2773							
10A2								0.40	0.40	0.127	0.037	-0.4679	0.9932	0.3852
10B1	2.00	1.96	0.850	0.242	1.0271	0.9915	0.2877							
10B2								1.03	1.11	0.142	0.041	0.9438	0.9782	0.6999
10C1	1.83	1.84	0.817	0.232	0.9442	0.9935	0.2773							
10C2								1.31	1.35	0.253	0.072	0.9786	0.9909	0.5694
10D 1		4.68	0.946	0.269	2.2004	1.0000	0.5456		3.83	0.592	0.168	2.1114	0.9877	0.6376
10D 2	1.64	1.67	0.279	0.080	1.2487	0.9938	0.6106	1.73	1.73	0.328	0.094	1.2291	0.9985	0.5664

Total air leakage (Q_t) continued

	Storm Window Up or Off							Storm Window Down or On						
	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef	Actual Q_0.30	Reg Q_0.30	Reg Q_0.016	ELA	Constant	R^2	X coef
11 A	0.67	0.68	0.059	0.017	0.6196	0.9809	0.8346							
11 B	0.42	0.45	0.071	0.020	-0.0384	0.9915	0.6296							
11 C	0.42	0.44	0.087	0.025	-0.1577	0.9865	0.5505							
11 D	0.56	0.54	0.116	0.033	-0.0039	0.9758	0.5189							
11 E	0.90	0.89	0.097	0.027	0.7947	0.9926	0.7580							
11 F	0.40	0.40	0.070	0.019	-0.2217	0.9876	0.5904							
12 A		4.65	1.051	0.299	2.1488	0.9528	0.5076		3.50	0.533	0.152	2.0234	0.9983	0.6417
12 B		2.67	0.399	0.113	1.7625	0.9820	0.6486		2.63	0.379	0.108	1.7623	0.9890	0.6606
12 C	2.12	2.16	0.267	0.076	1.6293	0.9936	0.7134	2.12	2.14	0.283	0.081	1.5924	0.9961	0.6906
12 D		2.59	0.271	0.077	1.8814	0.9924	0.7710		2.56	0.280	0.080	1.8481	0.9874	0.7548
12 E		3.31	0.550	0.156	1.9362	0.9978	0.6128		3.50	0.352	0.100	2.1940	0.9866	0.7832
12 F	1.61	1.75	0.137	0.039	1.6152	0.9915	0.8723	1.61	1.73	0.130	0.037	1.6154	0.9922	0.8832
12 G		4.32	0.524	0.150	2.3291	0.9944	0.7193		3.67	0.453	0.129	2.1571	0.9978	0.7131
12 H		4.91	0.832	0.237	2.3182	0.9989	0.6053		3.05	0.409	0.116	1.9369	0.9845	0.6847
12 I		5.20	0.972	0.277	2.3376	0.9999	0.5722		3.40	0.593	0.169	1.9402	0.9961	0.5956
12 J														
13 A		3.65	0.718	0.204	1.9619	0.9998	0.5538		2.54	0.519	0.147	1.5831	0.9992	0.5415
13 B		3.37	0.665	0.189	1.8816	0.9984	0.5537		2.79	0.394	0.112	1.8262	0.9792	0.6668
13 C		5.42	1.202	0.342	2.3081	1.0000	0.5136		4.73	0.749	0.213	2.3113	0.9987	0.6289
13 D		3.51	0.742	0.211	1.8930	0.9951	0.5299		3.07	0.650	0.185	1.7562	0.9827	0.5289
13 E		3.02	0.661	0.188	1.7325	0.9844	0.5191		2.66	0.483	0.138	1.6781	0.9924	0.5820
13 F		2.96	0.726	0.207	1.6641	0.9665	0.4797		2.91	0.540	0.154	1.7567	0.9964	0.5737
13 G		3.39	0.627	0.179	1.9115	0.9976	0.5748		3.01	0.586	0.167	1.7767	0.9939	0.5588
13 H		4.32	0.543	0.155	2.3145	0.9963	0.7072		3.46	0.507	0.144	2.0336	0.9881	0.6564
13 I		3.43	0.678	0.193	1.9004	0.9984	0.5537		2.93	0.593	0.169	1.7314	0.9966	0.5450
13 J	2.04	2.13	0.277	0.079	1.5943	0.9928	0.6963	1.99	2.07	0.236	0.067	1.6196	0.9786	0.7411
14 A	1.74	1.71	0.296	0.070	1.3329	0.9803	0.6631	1.13	1.13	0.096	0.027	1.1369	0.9908	0.8423
14 B		3.13	0.670	0.190	1.7755	0.9762	0.5260	1.69	1.61	0.238	0.068	1.2681	0.9947	0.6543
14 C		2.75	0.449	0.127	1.7591	0.9978	0.6194	1.69	1.75	0.215	0.061	1.4260	0.9911	0.7164
14 D	1.41	1.57	0.158	0.045	1.3896	0.9727	0.7813	1.01	0.99	0.117	0.033	0.8734	0.9947	0.7302
14 E	2.23	2.16	0.618	0.175	1.2855	0.9950	0.4275	0.57	0.59	0.114	0.032	0.1482	0.9909	0.5618
14 F		2.16	0.582	0.166	1.3115	0.9785	0.4481	0.42	0.42	0.097	0.028	-0.2857	0.9991	0.4995
15 A 1									6.16	1.250	0.355	2.4708	1.0000	0.5435
15 A 2								0.31	0.32	0.135	0.039	-0.7846	0.9833	0.2954
15 B 1		5.43	1.092	0.311	2.3519	1.0000	0.5474		3.94	1.025	0.292	1.8226	0.9814	0.4588
15 B 2								0.36	0.36	0.144	0.041	-0.6594	0.9742	0.3097
15 C 1														
15 C 2								0.42	0.41	0.245	0.070	-0.6771	0.9787	0.1756
15 D 1									6.08	1.288	0.366	2.4415	1.0000	0.5291
15 D 2								0.26	0.26	0.085	0.025	-0.8961	0.9916	0.3785
16 A									4.75	0.823	0.235	2.2778	1.0000	0.5978
16 B									2.97	1.140	0.324	1.4830	1.0000	0.3270
16 C												0.0733		
16 D												0.0733		
16 E		4.87	1.023	0.291	2.2263	0.9984	0.5329					0.0733		
16 F		5.47	0.965	0.280	2.4033	1.0000	0.5850					0.0733		
16 G		4.30	0.731	0.208	2.1866	0.9995	0.6046					0.0733		
17 A	2.43	2.44	0.477	0.136	1.5617	0.9939	0.5568	2.43	2.49	0.399	0.113	1.6595	0.9946	0.6236
17 B	2.08	2.20	0.311	0.088	1.5905	0.9930	0.6673	1.99	2.09	0.293	0.083	1.5446	0.9948	0.6711
17 C	2.66	2.66	0.566	0.160	1.6109	0.9852	0.5273	2.49	2.58	0.468	0.133	1.6527	0.9870	0.5831
18 A	0.87	0.85	0.096	0.027	0.7280	0.9956	0.7427					0.0733		
18 B	0.70	0.65	0.100	0.028	0.3280	0.9942	0.6364					0.0733		
19 A	1.66	1.72	0.244	0.069	1.3503	0.9903	0.6677	1.54	1.61	0.224	0.063	1.2883	0.9886	0.6738
19 B	1.27	1.31	0.157	0.044	1.1439	0.9907	0.7247	1.10	1.13	0.136	0.039	0.9865	0.9967	0.7247

8c. Numerical Conversions and Transformations

8c i. Data standardization

Air flow measurements (Q_t and Q_e) were recorded in "actual cubic feet per minute" (acfm) under ambient conditions. The sash flow difference (Q_s) was converted to "standard cubic feet per minute" (scfm) by the following formula, based on standard reference conditions listed in ASTM E 783-93:

$$scfm = acfm * \frac{293.8\ K}{273\ K + \frac{(^{\circ}F - 32) * 5}{9}} * \frac{atm\ P}{760 mm\ Hg}$$

The unit scfm was referenced to standard conditions at 20.8°C (293.8 Kelvin) and one atmosphere of pressure (760 mm Hg), meaning readings in scfm would generally be larger than readings in acfm due to the cooler ambient air temperatures. Converting to scfm allowed for valid comparisons of air leakage between windows of equal sizes tested under differing environmental conditions.

8c ii. Standard cubic feet per minute per linear foot crack

Windows were found in varying dimensions and comparison of leakage rates through different sized windows was therefore not valid. As an example, the larger of two window with identical leakage characteristics excepting size, would always show a larger leakage rate at a given pressure differential than the smaller window due to its larger operable crack length. A method of standardizing window size was employed to remove size bias. This was accomplished by expressing Q_5 as standard cubic feet per minute per linear foot crack (scfm/lfc) which represented the amount of air flowing through a unit length of operable window crack. Operable crack was defined as the meeting rail and junctures between movable sash and jambs. For a double-hung window, the formula for operable linear foot crack (lfc) was:

$$lfc = \frac{(2 * Height + 3 * Width)}{12 in./ft}$$

where *height* and *width* were the window dimensions in inches. The linear foot crack number (lfc) was divided into the appropriate flow rate (generally Q_5) to obtain scfm/lfc, a number descriptive of the leakage characteristics of the window independent of temperature, pressure, and window size. The standardized flow rates per operable linear crack (scfm/lfc) were listed for the pressure differentials attained for each window and were the numbers normally used for comparative purposes.

8c iii. Standard cubic feet per minute per square foot of sash area

A second method of presenting a standardized leakage rate was as standard cubic feet per minute per square foot of sash area (scfm/ft^2). The formula for the sash area of a double-hung window was:

$$\textit{Sash Area}\ (ft^2) = \frac{(\textit{Height} * \textit{Width})}{144\, in.^2/ft^2}$$

where *height* and *width* were the window dimensions in inches. Once again, this number was divided into the appropriate flow rate to attain the standard flow per square foot of sash area (scfm/ft^2).

When more than one type of window is in a house (ie. double-hung and casement windows) and windows are being compared to one another, the flow per sash area (scfm/ft^2) may be both more appropriate and accurate. This is due to the operating characteristics of differing window types. Double- and single-hung windows of identical size showing equivalent leakage rates when expressed as scfm/lfc do not have equivalent flows when viewed as total air leakage through the sash. The flow through a double-hung window is approximately 70% greater than the flow through a single-hung window of equal size as an allowance is given for the increased operable crack length in a double-hung window. (Most manufacturers of new windows list air infiltration data in terms of scfm/lfc, however, regardless of the window type.)

8c iv. Effective leakage area

A third comparative method and also used in the LBL correlation model was the effective leakage area (ELA). The ELA was used to characterize the natural air infiltration of a building at a pressure differential of 0.016 inches of water pressure. Extrapolation to the reference pressure was based field data fitted to the standard flow formula:

$$Q = c * \Delta P^x$$

where

- Q = air leakage in scfm or scfm/lfc
- ΔP = pressure differential
- *c* = leakage coefficient
- x = leakage exponent

Characterization of the leakage was accomplished by equilibrating the measured air leakage to an opening of a specific area that allows an equivalent leakage. Both x and c are regression coefficients determined from linear regression. ELA calculation is detailed in ASTM E 779-87, *Standard Test Method for Determining Air Leakage Rate by Fan Pressurization,* and was used to characterize air leakage rates through windows for the purposes of this project. Use of an ELA value allowed air openings in a window to be expressed as one total area for comparative purposes. Flow rates for all windows were converted to standard cubic feet per minute per linear foot crack (scfm/lfc) prior to ELA calculation to facilitate comparisons between windows of differing dimensions and varying environmental conditions.

ASTM E 779-87 lists a conventional reference pressure of 4 Pascals (Pa), equivalent to 0.016 inches of water pressure. Both metric (SI) and conventional (inch-pound, IP) formulations are given by ASTM for calculating ELA with the metric formulation being the preferred format. Calculated ELA's used in the study were based on the IP formula as most data had been recorded in IP units. Both formulations yield equivalent results when converted to common units. The IP formula is given below:

$$ELA = 0.1855 * c * \Delta P^{(x-0.5)} * (\rho_e/2)^{0.5}$$

where

ELA = equivalent leakage area (square inches)
c = leakage coefficient from linear regression
x = leakage exponent from linear regression
ΔP = 0.016 inches of water pressure
ρ_e = 0.07517 lbm/ft^3 (the density of air)
0.1855 = conversion factor

8d. Data Sheet Interpretation

An example of the transformed air leakage data for an individual window is found on the page *Reference Data Sheet* Window identification and a brief description are found on line 17. Above that are the relevant parameters necessary for standardization of the air flow. Block B22 through 629 are the pressure differentials in inches of water pressure used during a test run. Block B 30 (0.016 in. H_20) is equivalent to 4 Pa, the standard reference pressure for ELA's. The 0.016 inches of water pressure differential was assumed to be the annual average heating season differential between interior and exterior pressures and was assumed to be the driving force for natural infiltration. This value was used to compute the effective leakage area (ELA). Window manufacturers report test results at 0.30 inches of water pressure for new windows, equivalent to 75 Pascals. This pressure, 0.30 inches of water, is the reference pressure used in this summation so as to allow comparison with replacement windows.

Blocks C22-29 and 022-29 are the total air flows and extraneous air flows respectively with the storm window open, both expressed as actual cubic feet per minute (acfm). Block E22-29 is the sash flow in standard cubic feet per minute (scfm). Block F22 through H29 shows the same flows for the window with the storm window closed.

Window dimensions are found in block 122 to J23 and were used to standardize the sash flows (Qs) to standard cubic foot per minute per linear foot crack (scfm/Ifc) or per square foot (scfm/ft^2). Standardized sash flow per linear foot crack data are found in block K22 to N29 for windows with storm windows both open and closed.

The mathematical model used to describe the induced flow of air through the window is a widely used model for air flow:

$$Q_s = c * \Delta P^x$$

where

ΔP = pressure differential
c = leakage coefficient
x = leakage exponent.

The variables x and *c* need to be determined, but the model as written mathematically describes half a parabola. A natural logarithmic transformation linearizes the data, allowing x and *c* to be determined by linear regression. Linear regression compares data to a straight line. This transformation linearizes the data in the following manner:

$$Q_s = c * \Delta P^x$$
$$lnQ_s = 1nc + x * 1n\Delta P$$

which is analogous to the straight line equation:

$$y = b + mx$$

where

In c = constant, b (the y intercept)
x = x coefficient, m (the slope)

Blocks B34-42, D34-42, and J34-42 are respectively, the natural logarithms of the pressure differentials and scfm/lfc's for windows with storms open and closed. Linear regression was performed on these data to determine *c* (Constant) and x (X Coefficient), found in block E33 to H41. Linear regression also provided an estimate of how well the data fit the model, known as the goodness-of-fit value (R^2). The closer this value is to 1.000, the better the data fit the model.

The *x* and *c* values, along with the pressure differentials, were used to determine "best fit" data based on the mathematical model. It was these data that were usually used for comparative purposes as opposed to the raw data, due to the leaky nature of many windows tested. These data are found in block P22 to Q30, with P30 and Q30 being the values at 0.016 inches of water pressure (4 Pa).

The regression coefficients *x* and *c* were used with the reference pressure 0.016 inches of water to calculate the effective leakage area in square inches (ELA) as previously described. This value is found in block P34 to Q34. To gain a better understanding of the size of the effective leakage area, the ELA was assumed to be a square with the length of one side given in block P37 to 037.

Reference Data Sheet

B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
File:	DERBY.WB2														
Date:	08/13/96							Q_s, scfm/lfc							
								DERBY.WB2							
		Address:	Kidder Hotel Block												
			Derby, Vermont												
		Test Date:	04/29/96	and	04/30/96										
		Window Upgrade:	Six original pin-type windows, pins removed. New Harvey storm windows in place - four exterior, two interior.												
		Window Type:	Double hung, single glazed with Harvey triple track storms.												
Date:	04/29/96														
T (F):	50														
P (mm Hg):	758.2														
Window ID:	14 A		Exterior Harvey aluminum triple track storm window caulked in place.												
														Best Fit Data	
Pressure		Storm off			Storm on				Storm off		Storm on			Storm off	Storm on
Dif	Q_t	Q_e	Q_s	Q_t	Q_e	Q_s	Dimensions		Q_s	Q_s	Q_s	Q_s		Q_s	Q_s
(in. H2O)	(acfm)	(acfm)	(scfm)	(acfm)	(acfm)	(scfm)		(inches)	(scfm/lfc)	(scfm/ft^2)	(scfm/lfc)	(scfm/ft^2)		(scfm/lfc)	(scfm/lfc)
0.30	31	17	13.5	20	17	2.9	H =	60	0.73	0.97	0.16	0.21		0.78	0.24
0.25	28	15	12.5	18	15	2.9	W =	33.5	0.68	0.90	0.16	0.21		0.70	0.18
0.20	25	14	10.6	16	14	1.9			0.58	0.76	0.10	0.14		0.62	0.12
0.15	21	9.9	10.7	13	9.9	3.0			0.58	0.77	0.16	0.21		0.53	0.08
0.10	17	7.5	9.1	8.5	7.5	1.0			0.50	0.66	0.05	0.07		0.42	0.04
0.07	13	5.6	7.1	6.4	5.6	0.8			0.39	0.51	0.04	0.06		0.35	0.02
0.05	8.9	4.4	4.3	4.5	4.4	0.1			0.24	0.31	0.005	0.007		0.29	0.01
0.03	6.4													0.22	0.01
0.016														0.154	0.002
				Storm off						Storm on				ELA	ELA
ln P		ln Q_s		Regression Output:				ln Q_s		Regression Output:				(in^2)	(in^2)
-1.20397		-0.31026	Constant			0.409693		-1.85071	Constant			0.538255		0.044	0.001
-1.38629		-0.38437	Std Err of Y Est			0.139705		-1.85071	Std Err of Y Est			0.640686			
-1.60944		-0.55142	R Squared			0.89337		-2.25617	R Squared			0.777068		Side of square (in.)	
-1.89712		-0.54237	No. of Observations			7		-1.81792	No. of Observations			7		0.21	0.02
-2.30259		-0.69803	Degrees of Freedom			5		-2.94932	Degrees of Freedom			5			
-2.65926		-0.94784						-3.17246							
-2.99573		-1.44524	X Coefficient(s)		0.551242			-5.2519	X Coefficient(s)		1.63059				
-3.50656			Std Err of Coef.		0.085169				Std Err of Coef.		0.390585				
-4.13517															

8e. Field Data Sheets

8e i. Window data sheet

Date: ________ Time ________
Project Name: ________________________ Location: ______________________________

Orientation ___________
Temperature (°F) - Interior T_{dry} -_____ T_{wet} - _____ Exterior T_{dry} - _____ T_{wet} - _____
P_{atm} (mm Hg): _______ Wind: speed (mph) - _____ direction - _____

Window type: ____________________ Single pane: _____
Multipane: ______ x ______
Pane Size (in) - ______ x ______

Dimensions (in.) : Total Height - ________ Sash Width - ________
Upper Sash - ________ Sash Depth - ________
Lower Sash - ________

Window weight cavity: Y N Connected? Y N

Locking mechanism: Y N Operable: Y N NA
Type ______________________ Location(s) _____________________________________

Storm Window Type: None | Aluminum triple track | Aluminum double track | Wood sash | Other: _______ _______ _______

Comments: ____
____
____
____
____

	Storms up or no storms		Storms down	
ΔP (in H20	Q_t (acfm)	Q_e (acfm)	Q_t (acfm)	Q_e (acfm)
0.30				
0.25				
0.20				
0.15				
0.10				
0.07				
0.05				
0.03				

8e ii. Physical condition check sheet

Physical condition		Excellent									Poor
Upper Sash											
	Putty condition	10	9	8	7	6	5	4	3	2	1
	Glass tight	10	9	8	7	6	5	4	3	2	1
	Fit to frame	10	9	8	7	6	5	4	3	2	1
	Square in frame	10	9	8	7	6	5	4	3	2	1
Lower Sash											
	Putty condition	10	9	8	7	6	5	4	3	2	1
	Glass tight	10	9	8	7	6	5	4	3	2	1
	Fit to frame	10	9	8	7	6	5	4	3	2	1
	Square in frame	10	9	8	7	6	5	4	3	2	1
Frame											
	Stops tight	10	9	8	7	6	5	4	3	2	1
	Tight to trim	10	9	8	7	6	5	4	3	2	1
Meeting Rail											
	Tight fit	10	9	8	7	6	5	4	3	2	1
Exterior caulking		10	9	8	7	6	5	4	3	2	1

8e iii. Physical condition criteria

Upper and Lower Sash

Putty Condition - Generally, it is the bottom glazing of each sash that weathers most quickly and it is this border that is the primary determinant for putty condition.

10 - Relatively new putty with no cracks.
9-7 - Putty is intact but has varying degrees of cracks.
6-4 - Putty is intact but obviously dried out, large cracks, some flaking apparent.
3-2 - Portions of the putty missing, less than one inch total.
1 - Greater than one aggregate linear inch of putty missing or a gap between the glass and sash is evident.

Glass Tightness - This is very much a function of the putty condition and the putty condition number is considered when determining tightness. Overall tightness is determined by tapping around the perimeter(s) of the glass pane(s). Caution is taken to ensure that only the sash being tapped is causing any vibratory noise.

10-7 - Glass shows little to no vibrations.
6-4 - Glass vibrates and sounds loose.
3-1 - Glass visibly moves under slight pressure. A putty condition of 1 by definition has a glass tightness of 1.

Fit to Frame - This is a combination of visual and physical inspections. The sash is visually inspected for gaps between the jambs and sash and the lower sash is viewed from above for gap symmetry on either edge. Each sash is physically moved from side to side and front to back while unlatched to subjectively determine play.

10-8 - No gaps, fairly symmetrical, little play in either direction.
7-5 - No gaps, somewhat asymmetrical, play in either direction is becoming pronounced.
4-3 - Small gaps are apparent, sash may be asymmetrical, significant lateral play.
2-1 - Easily noticeable gaps, sash readily moves laterally.

Square in Frame - Squareness is also incorporated in Fit to Frame but is also important enough to warrant its own category and is visually determined relative to the jambs and parting beads if present.

10-8 -Sash appears square with exposed stiles being symmetrical and rails being horizontal.
7-4 - Sash is skewed up to 1/4 inch with exposed stiles being asymmetrical.
3-1 - Sash is skewed more than 1/4 inch.

Frame

Stops Tight - This is determined both visually and physically by tapping the stops and listening for vibrations. Paint also is a consideration. Stops are not considered individually but as a unit.

10-8 - Stops are flush to jambs with no discernable vibration when tapped. Wood may be painted with little to no cracking of the paint along the stop edge.

7-5 - Stops vibrate when tapped and have visible cracks up to approximately
1/16 inch for 1/4 aggregate stop length.

4-2 - Stops vibrate freely when tapped and have cracks up to approximately
1/8 inch for 1/4 to 1/2 aggregate stop length.

1 - Stops are missing or not held in place and may fall when tapped. Gaps greater than 1/8 inch are present.

Tight to Trim - Determined by visual inspection of the trim to wall juncture.

10-8 - No visible crack to a hairline crack being apparent around any portion of the trim.

7-5 - Narrow crack around 1/4 to 1/2 of trim.

4-3 - Crack extends around entire frame and varies in width.

2-1 - Crack is large (1/8 inch); frame is not flush with the wall.

Meeting Rail

Tight Fit - The meeting rail is examined while sashes are latched (when latches are present and operable) as this is the expected normal winter operating mode. The interface of the sashes is examined for tightness and whether the upper and lower sashes are horizontal and flush in the vertical direction or are skewed

10-8 - Horizontal, flush, and with a tight interface.

7-4 - Horizontal but not flush and/or slightly skewed with an interface that is not tight for the entire length.

3-1- Meeting rail is neither horizontal nor flush with an interface that does not fully meet or exhibits poor juncture.

Exterior Caulking - A visual inspection is done to ensure all exterior portions of the window unit are present as well as the window unit/exterior wall caulking.

10-8 - Caulking appears to be intact and in good condition.

7-5 - Caulking appears dry and weathered with cracks and minor flaking apparent.

4-2 - Caulking is crumbling, flaky, and missing in areas.

1 - Some exterior window segments are missing as well as large amounts of caulking

8f. Equations for Weather Parameters Based on Psychrometric Data

Calculations to determine dew point temperature (td) and partial water vapor pressure (p_w) given field measurements of weather parameters dry-bulb temperature (t), wet-bulb temperature (t*), and atmospheric pressure (p):

Absolute temperature, T_{abs} or T^*_{abs} (in degrees Rankine):

$$T_{abs} = t + 459.67$$

or

$$T^*_{abs} = t^* + 459.67$$

where

t = dry-bulb temperature (^oF)

t^* = wet-bulb temperature (^oF)

Natural logarithm of the saturation water vapor pressure, p^*_{ws}, at T^*_{abs})

$$\ln(p^*_{ws}) = \frac{C_1}{T^*_{abs}} + C_2 + C_3 * T^*_{abs} + C_4 * (T^*_{abs})^2 + C_5 * (T^*_{abs})^3 + C_6 * (\ln T^*_{abs})$$

where

$C_1 = -1.044039708 * 10^4$

$C_2 = -1.12946496 * 10^1$

$C_3 = -2.7022355 * 10^{-2}$

$C_4 = 1.2890360 * 10^{-5}$

$C_5 = -2.478068 * 10^{-9}$

$C_6 = 6.5459673$

Saturation humidity ratio, W^*_s, at the wet-bulb temperature, t^*:

$$W^*_s = 0.62198 * \frac{p^*_{ws}}{p - p^*_{ws}}$$

where

P^*_{ws} = saturation water vapor pressure

p = atmospheric pressure (psia)

Humidity ratio, W:

$$W = \frac{(1093 - 0.556t^*)W_s^* - 0.240(t - t^*)}{1093 + 0.444t - t^*}$$

where

W_s^* = *saturation humidity ratio*

t = *dry–bulb temperature* (°F)

t^* = *wet–bulb temperature* (°F)

Partial pressure of water vapor, p_w, for moist air:

$$p_w = \frac{p * W}{0.62198 + W}$$

where

p = *atmospheric pressure* (*psia*)

W = *humidity ratio*

Dew point temperature, t_d:

$$t_d = 100.45 + 33.193 * (\ln p_w) + 2.319 * (\ln p_w)^2 + 0.17074 * (\ln p_w)^3 + 1.2063 * (p_w)^{0.1984}$$

where

P_w = *partial water vapor pressure*

Calculations to determine relative humidity (0) given field measurements of weather parameters dry-bulb temperature (t), wet-bulb temperature (t°), and atmospheric pressure (p):

Natural logarithm of the saturation water vapor pressure, P_{ws}, at Tabs:

$$ln(p_{ws}) = \frac{C_1}{T_{abs}} + C_2 + C_3 * T_{abs} + C_4 * T_{abs}^2 + C_5 * T_{abs}^3 + C_6 * (ln\ T_{abs})$$

where

$$C_1 = -1.044039708 * 10^4$$
$$C_2 = -1.12946496 * 10^1$$
$$C_3 = -2.7022355 * 10^{-2}$$
$$C_4 = 1.2890360 * 10^{-5}$$
$$C_5 = -2.478068 * 10^{-9}$$
$$C_6 = 6.5459673$$

Saturation humidity ratio, W_s, at the dry-bulb temperature, t:

$$W_s = 0.62198 * \frac{p_{ws}}{p - p_{ws}}$$

where

p_{ws} = *saturation water vapor pressure at the dry-bulb temperature*

p = *atmospheric pressure (psia)*

Degree of saturation, p, at a given temperature and pressure (t, p):

$$\mu = \frac{W}{W_s}$$

where

W = *humidity ratio*

W_s = *saturation humidity ratio*

Relative humidity, Φ:

$$\phi = \frac{\mu}{1-(1-\mu)\frac{p_{ws}}{p}}$$

where -

μ = *degree of saturation*

P_{ws} = *saturation water vapor pressure at thy-bulb temperature*

P = *atmospheric pressure (psia)*

8g. Exterior Air

8g i. Determination of percent exterior air in Qe

Infiltration of exterior air not only occurred through the window sash and sash/frame junction (Q_s) but also through the rough opening as extraneous air (Q_e) adding to the heating load. Quantifying the volume of exterior air is important in understanding the total heat load due to a window The following field method was devised and implemented to approximate the volume of exterior air contained in the induced extraneous air leakage.

An estimate of the volume of exterior air coming through the rough opening may be calculated by knowing the temperature between the two sheets of plastic while testing for extraneous air (Q_e) along with the ambient exterior and interior air temperatures. Knowing these three data points and any measured value of Q_e, a mass balance on temperature and air flow may be performed to estimate the volume of exterior air in Q_e The volume of exterior air in Q_s was determined by the following formula:

$$Q_{ext} = \frac{Q_e * (T_{win} - T_{int})}{(T_{ext} - T_{int})}$$

where:

Q_{ext} = the volume of exterior air (acfm)
Q_e = the volume of air chosen from extraneous air test data (acfm)
T_{win}= the temperature between the two plastic sheets during the test (°F)
T_{int} = ambient interior air temperature (°F)
T_{ext} = ambient exterior air temperature (°F)

The volume of exterior air (Q_{ext}) was converted to a percentage by dividing through by Q_e. If the percentage of interior air (Q_{int}) in Q_e is desired, it may be calculated by subtracting the Q_{ext} percentage from 100%, or directly by the following formula if Q_{ext} is not known:

$$Q_{int} = \frac{Q_e * (T_{win} - T_{ext})}{(T_{int} - T_{ext})}$$

where the variables are the same as those in the previous equation.

The amount of exterior air entering through the rough opening was calculated for 36 windows at five different locales. Data from three windows in Irasburg (windows I 6E, I 6F, and 16G) were not included in an average value as direct sunlight had been heating the wall during the early to mid-morning period prior to testing. Testing of these three windows occurred while the wall was shaded but the calculated exterior air percentages (88%, 88%, and 67%) appeared abnormally large when compared to the other 33 windows. The assumption was made that the wall had not returned to the ambient air temperature prior to testing, and the data was discounted.

The average percentage of exterior air entering the buildings through the rough openings of 33 windows was 29%, meaning approximately 30% of the measured air in the Qe test must be heated during the heating season and must count towards the heating load of a typical window. The percentage of exterior air in Qe for the 33 windows is summarized in the following table:

Table g.1: Percentage of Q_{ext} in Q_e for 33 windows

Average value of Q_{ext}	28.6%
Maximum value of Q_{ext}	54.5%
Minimum value of Q_{ext}	7.7%

Both pin- and pulley-type windows were included in the 33 windows, with pin type windows averaging 26% exterior air passing through the rough opening versus 31 % for the pulley-type windows.

Of the 33 windows used to estimate a typical value for the percentage of exterior air in Q_e, all but two were the original sash after refurbishing. Windows 12B and 12C were both in-kind replacement sash with vinyl jamb liners. Both replacement windows have low exterior air percentages (12.5% and 13.2%), although some original sash windows (7B2, 702, 12F, 13B, 14B, 14C. and 14D) are of equivalent tightness in terms of Q_{ext}

This method of estimating the volume of exterior air entering the test zone during testing periods has severe limitations and values thus derived should not be assumed to be accurate. Temperatures in the test zone stabilized within a minute, but it is unknown whether steady state conditions had been reached within the building walls. No attempt was made to determine the actual air path through the wall cavities while a window was under pressure. Exterior air likely increased its temperature as it passed through walls warmer than the ambient exterior atmospheric temperature, raising questions as to the accuracy of the temperature readings in the test zone. The method was used to determine a rough approximation of the contribution of extraneous air to the overall heating load.

8g ii. Experimental data used to determine percentage exterior air

Window ID	T_{int} (^oF)	T_{win} (^oF)	T_{ext} (^oF)	Q_e (acfm)	Q_{ext} (acfm)	Percent Ext. Air
7A2	62	58	48	32	9.1	28.6
7B2	61	60	48	42	3.2	7.7
7C2	65	61	53	18	6.0	33.3
7D2	65	59	53	9.7	4.9	50.0
7E2	63	59	52	30	10.9	36.4
7F2	60	57	52	20	7.5	37.5
7G2	60	58	54	19	6.3	33.3
7J2	58	51	38	18	6.3	35.0
7K2	62	56	39	20	5.2	26.1
7L2	62	55	41	17	5.7	33.3
7M2	61	56	44	20	5.9	29.4
7N2	62	57	46	25	7.8	31.3
7O2	60	58	48	31	5.2	16.7
7P2	61	57	51	20	8.0	40.0
7Q2	60	58	51	40	8.9	22.2
12A	70	61	51	40	18.9	47.4
12B	72	69	48	40	5.0	12.5
12C	71	66	33	29	3.8	13.2
12F	71	68	51	22	3.3	15.0
12G	69	60	46	22	8.6	39.1
12H	71	62	46	38	13.7	36.0
12I	72	63	45	37	12.3	33.3
12J	71	66	44	39	7.2	18.5
13A	71	66	54	35	10.3	29.4
13B	70	68	56	34	4.9	14.3
13G	69	64	50	38	10.0	26.3
14B	65	63	50	25	3.3	13.3
14C	64	62	52	24	4.0	16.7
14D	64	62	50	15	2.1	14.3
14E	62	57	49	20	7.7	38.5
14F	62	56	51	19	10.4	54.5
14F2	60	58	51	7.56	1.7	22.2
16B	54	57	62	36	13.5	37.5
16E**	63	68	69	33	27.5	83.3
16F**	65	70	71	31	25.8	83.3
16G**	65	69	71	39	26.0	66.7

**Wall may still be retaining heat from direct sunlight. Data excluded.

8h. Assumptions for using WINDOW 4.1

All windows modeled are double-hung (vertical sliders) measuring 36 x 60 inches. Interior and exterior temperatures were 70°F and 0°F respectively, with a 15 mph wind blowing. Assumed typical and tight window parameters:

1. wood sash;
2. double-glazed with second layer consisting of a storm window 2.5 inches from primary sash (average distance between storm and upper and lower primary sash) Glass is clear with air between glazing layers.

Assumed loose window parameters:

1. wood sash:
2. single-glazed with no storm window. Glass is clear

In-kind, two over two replacement sash parameters:

1. wood sash,
2. double-glazed with second layer consisting of a storm window 2.5 inches from primary sash (average distance between storm and upper and lower primary sash) Glass is clear with air between glazing layers.

Double-pane insulating glass replacement window insert parameters:

1a. wood sash:
2a. double-glazed with second layer 0 500 inches from primary sash. Glass is clear with air between glazing layers

1b. vinyl sash;
2b. double-glazed with second layer 0.500 inches from primary sash. Glass is clear with air between glazing layers.

The following windows were modeled using WINDOW 4.1 but were not encountered in the field:

1. low-e replacement sash with standard storm window;
2. standard replacement sash with low-e storm window;
3. replacement sash with double-glazed Iow-e insulating glass; and
4. replacement window inserts with low-e double-glazed insulating glass.

8i. LBL Correlation Model Computer Printout

Volume	30,000	22,900	
Pressure		Flow, cfm	
4 Pa		2.069	
4 Pa ELA	1.480	(in²)	0.588
	33	% of leakage area in ceiling	
	33	% of leakage area in floor	
	34	% of leakage area in all 4 walls	
Ao	0.000955	total leakage area (m²)	
Ac	0.000315	leakage area in the ceiling (m²)	
Af	0.000315	leakage area in the floor (m²)	
R	0.6600		
X	0.0000		
	19	height of the roof (ft)	
H	5.7912	height of the roof (m)	
y	0.23	terrain parameter #1 (see table)	
a	0.73	terrain parameter #2 (see table)	
fT	0.757	terrain factor	
C'	0.24	shielding coefficient (see table)	
fW	0.1675	wind parameter	
f'W	0.1269	reduced wind parameter	
fs	0.4433	stack parameter	
Volume	30000	(ft^3)	
Volume	849.6	(m^3)	
Ti	68	Winter Indoor Avg. Temp. (°F)	

Site 12, storm windows closed

ELA_tot = 1.48 in^2

Q_net = 2.069 scfm

Month	ACH	Qtot (m^3/se	Qwind (m^3/sec)	Qstack (m^3/sec)	VT-wind V'	v's	f's	TiF	VT-temp ToF	TiK	ToK
JAN	0.0047	0.0011	0.0005	0.0010	4.25	1.04	0.20	68	17	293.2	264.9
FEB	0.0046	0.0011	0.0005	0.0010	4.11	1.02	0.20	68	19	293.2	266.0
MAR	0.0043	0.0010	0.0005	0.0009	4.20	0.91	0.20	68	29	293.2	271.5
APR	0.0036	0.0009	0.0005	0.0007	4.16	0.73	0.20	68	43	293.2	279.3
MAY	0.0029	0.0007	0.0005	0.0006	3.93	0.52	0.20	68	55	293.2	286.0
JUN	0.0023	0.0005	0.0004	0.0003	3.71	0.32	0.19	70	65	294.3	291.5
JUL	0.0022	0.0005	0.0004	0.0003	3.53	0.32	0.19	75	70	297.1	294.3
AUG	0.0021	0.0005	0.0004	0.0003	3.31	0.32	0.19	72	67	295.4	292.6
SEP	0.0026	0.0006	0.0004	0.0004	3.62	0.44	0.20	68	59	293.2	288.2
OCT	0.0032	0.0008	0.0005	0.0006	3.84	0.63	0.20	68	49	293.2	282.6
NOV	0.0039	0.0009	0.0005	0.0008	4.25	0.81	0.20	68	37	293.2	276.0
DEC	0.0045	0.0011	0.0005	0.0009	4.38	0.98	0.20	68	23	293.2	268.2
Average Annual	0.0034	0.0008	0.0005	0.0006							
Oct-Apr Average	0.0041	0.0010	0.0005	0.0008							

Burlington Avg Tem	Avg DDays		
15	1,494	0.192924	JAN
17	1,299	0.167743	FEB
19	1,113	0.143724	MAR
29	660	0.085227	APR
43	331	0.042743	MAY
		0	JUN
		0	JUL
		0	AUG
59	191	0.024664	SEP
49	502	0.064824	OCT
37	840	0.108471	NOV
23	1314	0.16968	DEC
	7744	0.004207	
DDay weighted avg			

AVERAGE PREDICTED INFILTRATION RATES

TEST DATE: 06/28/94

	Air Changes per Hour	Average cfm
Average Annual	0.0034	1.715
Oct-Apr Average	0.0041	2.069
	Wind-Driven	Stack-Driven
Average Annual	43%	57%
Oct-Apr Average	38%	62%

What Replacement Windows Can't Replace: The Real Cost of Removing Historic Windows

WALTER SEDOVIC and JILL H. GOTTHELF

Sustainability looks even better through a restored window.

	EMBODIED ENERGY	
MATERIALS	MJ/kg	MJ/m3
Aggregate	0.10	150
Straw bale	0.24	31
Soil-cement	0.42	819
Stone (local)	0.79	2030
Concrete block	0.94	2350
Concrete (30 Mpa)	1.3	3180
Concrete precast	2.0	2780
Lumber	2.5	1380
Brick	2.5	5170
Cellulose insulation	3.3	112
Gypsum wallboard	6.1	5890
Particle board	8.0	4400
Aluminum (recycled)	8.1	21870
Steel (recycled)	8.9	37210
Shingles (asphalt)	9.0	4930
Plywood	10.4	5720
Mineral wool insulation	14.6	139
Glass	15.9	37550
Fiberglass insulation	30.3	970
Steel	32.0	251200
Zinc	51.0	371280
Brass	62.0	519560
PVC	70.0	93620
Copper	70.6	631164
Paint	93.3	117500
Linoleum	116.0	150930
Polystyrene Insulation	117.0	3770
Carpet (synthetic)	148.0	84900
Aluminum (recycled)	227.0	515700
NOTE: Embodied energy values based on several international sources - local values may vary.		

Fig. 1. Comparative values of the embodied-energy levels of common building materials. Note that glass and aluminum (i.e., principal components of many replacement windows) are ranked among the highest levels of embodied energy, while most historic materials tend to possess much lower levels. Courtesy of Ted Kesik, Canadian Architect's Architectural Science Forum, Perspectives on Sustainability.

For all the brilliance reflected in efforts to preserve historic buildings in the U.S., the issue of replacing windows rather than restoring them remains singularly unresolved. Proponents on both sides of the issue may easily become frustrated by a dearth of useful data, as well as conflicting information, or misinformation, promulgated by manufacturers. Indeed, it often seems that many preservation practitioners and building owners remain in the sway of advertising claiming that the first order of business is to replace old windows. In the context of preservation and sustainability, however, it is well worth reconsidering this approach.

Sustainability and Authenticity

In considering alternatives to replacing historic windows, one needs to keep in mind two important elements: sustainability and authenticity. Sustainability (building green) and historic preservation are a natural marriage, so long as one remains mindful that sustainability is not just about energy conservation.[1] Preservation and sustainability involve myriad elements that can work in symbiotic and synchronized ways toward a favorable outcome. For example, preservation work is more labor- than material-intensive, which benefits local economies; natural ventilation afforded via operable windows can reduce the size of mechanical equipment, especially of air-conditioning; and salvaging historic materials, such as wood sash, obviates the need to harvest live trees and other natural resources for the manufacture of replacement units.

Similarly, retaining and celebrating authenticity is one key element of an exemplary preservation program. No one should take lightly the option of discarding authentic historic materials — in this case, windows — without fully evaluating the consequences. Once authentic material is lost, it is lost forever. It does not matter how accurate the replacement window, it never reflects the nuances of the original.

Taking the Long View

Historic windows possess aesthetic and material attributes that simply cannot be replaced by modern replacement windows. Like preserving whole buildings, restoring historic windows is a solid step forward into the realm of sustainability. The present approach to sustainability, however, still too often focuses on new construction and issues such as "intelligent" windows and energy efficiency, while overlooking other important, holistic benefits of preserving historic windows, such as the following:

- Conservation of embodied energy (i.e., the sum total of the energy required to extract raw materials, manufacture, transport, and install building products). Preserving historic windows not only conserves their embodied energy, it also eliminates the need to spend energy on replacement windows. Aluminum and vinyl — the materials used in many replacement windows — and new glass itself possess levels of embodied energy that are among the highest of most building materials (Fig. 1).[2]
- Reduction of environmental costs. Reusing historic windows reduces environmental costs by eliminating the need for removal and disposal of existing units, as well as manufacture and transportation of new units. Also, many replacement units are manufactured with such materials as

MISSOURI DEPARTMENT OF NATURAL RESOURCES
ENERGY CENTER - ENERGY LOAN PROGRAM
WINDOW REPLACEMENT WORKSHEET

BUILDING	LOCATION	DATE

To estimate the savings of replacing existing windows with efficiency upgrades, the following information must be known:

The U-Factor of the existing window (See U-Value table below).
The U-Factor of the replacement window (See U-Value table below).
The total area of the windows being replaced (square feet).
The heating energy cost ($/million Btu).
The heating plant efficiency (in percent).

SAVINGS CALCULATIONS

1. Enter the U-Factor of the existing windows........ ________
2. Enter the U-Factor of the replacement windows........ ________
3. Subtract line 2 from line 1........ ________
4. Add 0.86 to line 3........ ________
5. Enter the total area of the windows to be replaced........ ________
6. Multiply line 4 by line 5........ ________
7. Multiply 0.1 by line 6........ ________
8. Enter the heating plant efficiency (percent divided by 100)........ ________
9. Divide line 7 by line 8........ ________
10. Enter the energy cost ($/million Btu)........ ________

YEARLY SAVINGS

11. Multiply line 9 by line 10........ $ ________ /year

PROJECT COST

12. Enter the total cost of the window replacement including material, labor and design........ $ ________

SIMPLE PAYBACK

13. Divide line 12 by line 11........ ________ years

WINDOW U-VALUE TABLE

Window System Type	U-Factor*
Single Glass	1.10
Single Glass with storm window	0.50
Single Glass, low E coating	0.91
Single Glass, low E coating with storm window	0.44
Insulating Glass (double glass)	0.55
Insulating Glass (double glass) with storm window	0.35
Insulating Glass (double glass), low E coating	0.38
Insulating Glass (double glass), low E coating with storm window	0.32
Insulating Glass (triple glass)	0.35
Insulating glass (triple glass) with storm window	0.25

* U-Factor values adapted from the 1985 ASHRAE Fundamentals Handbook.

MO 780-1363 (5-98) DNR/TAREQV 3.5 (5-98)

Fig. 2. Many excellent worksheets are available for calculating payback of replacement windows; this one is produced by the Missouri Department of Natural Resources. Results of payback calculations often reveal grossly overstated claims. Courtesy of the Missouri Department of Natural Resources.

vinyl and PVC, whose production is known to produce toxic by-products. So, while energy savings is green, the vehicle toward its achievement — in this case, replacement windows — is likely to be the antithesis of green.[3]

- Economic benefits. Restoration projects are nearly twice as labor-intensive as new construction, meaning more dollars spent go to people, not materials. This type of spending, in turn, has the beneficial effect of producing stronger, more dynamic local economies.[4]
- Ease of maintenance. "Maintenance-free" is a convenient marketing slogan; many replacement windows, in reality, cannot be maintained well or conserved. Vinyl, fiberglass, sealants, desiccants, and coating systems all degrade, and they are materials that remain difficult or impossible to recycle or conserve.[5]
- Long-term performance. While manufacturers' warranties have been lengthened in the past few years (they are now generally from 2 to 10 years), they still pale in comparison to the actual performance life exhibited in historic windows, which can reach 60 to 100 years and more, often with just minimal maintenance.

Clearly, sustainability takes into account more than just the cost of energy savings. It also promotes salient social, economic, and environmental benefits, along with craftsmanship, aesthetics, and the cultural significance of historic fabric. Still, the issue of energy savings is often used to justify replacement over restoration, but just how valid is this argument?

Energy Savings

If the foremost goal for replacing historic windows is energy savings, beware of "facts" presented: they very likely will be — intentionally or not — skewed, misinformed, or outright fallacious. Window manufacturers universally boast about low U-values (the measure of the rate of heat loss through a material or assembly; a U-value is the reciprocal of an R-value, which is the measure of resistance to heat gain or loss). For example, U-values are often misleadingly quoted as the value for the entire window unit, when in fact it is the value through the center of the glass (the location of the best U-value), not that of the sash nor the average of the entire unit.[6] To be sure that data are being presented appropriately, request the U-values published by the National Fenestration Rating Council (NFRC), which rate whole-window performance.[7]

When U-values are offered for the entire window assembly, they often are significantly worse (i.e., higher) due to infiltration around the frame and rough opening.[8] In cases where replacements tend to warp and bow over time (and they do), this factor becomes ever more crucial.[9] It is also important to watch for comparative analyses: some replacement-window manufacturers compare their window units to an "equivalent" single-pane aluminum window. Clearly, this is an inappropriate analogy since these types of windows are not likely to be found in a preservation context.

Infiltration of Outside Air

Infiltration of outside air — rather than heat lost through the glass — is the principal culprit affecting energy; it can account for as much as 50 percent of the total heat loss of a building.[10] When retrofit windows are installed over or within the existing window frame, the argument for preservation already exists: restoring the integrity of the fit between the frame and building wall should be the first component of a preservation approach.

Sash pockets, pulleys, and meeting rails are areas prone to air infiltration in double-hung units. Yet, several weatherproofing systems for existing windows can overcome these heat-sapping short circuits.[11] Replacement-window manufacturers themselves admit that even among replacements, double-hung units present the greatest challenges for controlling heat loss because infiltration occurs most frequently at sash-to-sash and sash-to-frame interfaces, which are highly dependent on the quality of the installation.[12] The energy efficiency of restored windows incorporating retrofit components (weatherstripping and weatherseals combining pile, brush, bulb, or "Z" spring seals) can meet and even exceed the efficiency of replacement units.[13] This approach is suggested as the first alternative among green-building advocates.[14]

Payback

Focusing on windows as the principal source of heat transfer may lead to the conclusion that windows are more important than, say, insulating the attic, foundation, or walls. While data vary somewhat, up to 25 percent of heat may be lost through doors and windows.[15] But when the aforementioned potential 50 percent loss through infiltration is taken into account, the total effective percentage of heat loss attributed to the window units themselves would be only 12.5 percent. That is a relatively small percentage for a potentially large investment, especially when other options are available.

In actuality, typical window-replacement systems offer payback periods that are often nowhere near manufacturers' claims: the payback of a typical unit could take as long as 100 years (Fig. 2).[16]

Heat Loss/Heat Gain

Heat loss is often discussed, but what about heat gain? In summer, heat gain can add significantly to the energy costs associated with cooling a building.[17] Long waveforms within the daylight spectrum that enter through the glass must be able to exit, or else they degrade to heat that then must be overcome by the building's cooling system.[18] Low-emittance ("low-e" or "soft low-e") glass handles this task best, improving thermal performance by virtually eliminating infrared (long-wave) radiation through the window.[19] It accomplishes this task by allowing short-wave radiation through and reflecting long-wave heat back to its source, while at the same time providing an appearance that is virtually clear.[20]

Low-e glazing can be substituted into existing units that are only single-glazed and still achieve important energy savings. Single-pane low-e glass can provide a virtually equivalent level of combined energy savings as a standard new double-glazed unit when used in concert with an existing single-paned sash (e.g., as a storm or interior sash).[21] Replacing panes of glass, then tightening up the sash and frame, is a very simple and cost-effective way to achieve the desired whole-assembly U-value without having to modify visible light, mullions, or sash weights.[22]

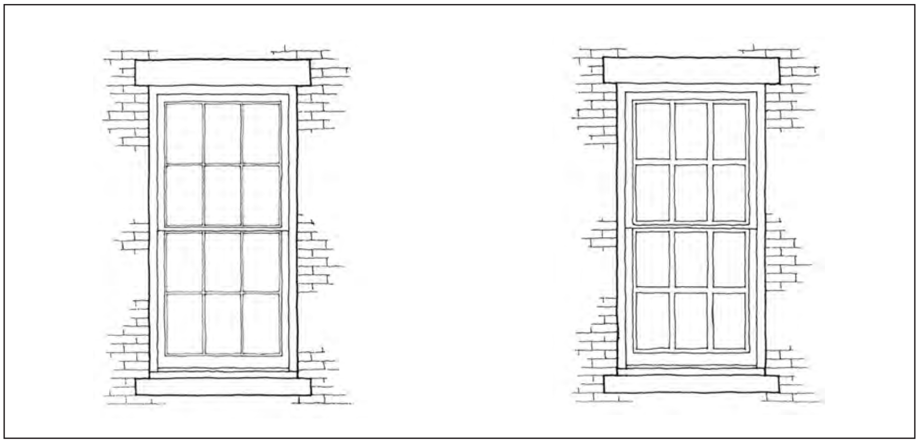

Fig. 3. At left is a drawing of a typical late-nineteenth- to early-twentieth-century six-over-six, double-hung window. At right is a modern "equivalent" replacement. The considerably thicker mullions and frame of the replacement unit (necessitated by the use of insulated glass) result in a nearly 15 percent reduction of visible light and views. Drawing by Walter Sedovic Architects.

Insulated Glass

Replacement windows nearly always incorporate insulated glass (IG) units. The effectiveness of an IG unit is greatly dependent on the depth of the airspace between inner and outer panes, as well as on the nature, type, and amount of desiccant and seals employed around the unit perimeter.[23] While manufacturing techniques for IG units have continued to improve, when IG units fail, they are difficult and time-consuming to replace.[24]

The additional weight and thickness of IG units preclude their use as retrofits in historic sashes of either wood or metal. Indeed, to compensate for their heft, virtually all IG replacement window mullions, sash, and frames are bulkier than their historic counterparts. The result is that visible daylight levels are reduced by 15 percent or more and views are interrupted.[25] Reducing daylight and negatively affecting views are explicitly not consistent with a sustainable approach (Fig. 3).

Laminated Glass as an Alternative

Laminated glass remains an often-overlooked alternative to IG units, perhaps because of the industry's focus on marketing it as "safety" glass. While laminated glass cannot compete with technologically advanced, complex IG units, it does offer enhanced U-values for monolithic glass without having to materially alter the mullions of the historic sash into which it is being fitted.[26] It is important to recognize, though, that a U-value is not the only criterion that determines the relative thermal efficiency of a window. Solar and light transmittance also affect performance, and they may be benefit when low-e laminated glass is selected.[27] The benefits of laminated glass, though, go much further when considered part of a comprehensive program to restore and thermally upgrade historic sash:

- Laminated glass offers significantly higher levels of noise abatement than IG.
- Historic glass may be laminated, offering energy and noise benefits while maintaining an authentic finish.
- Laminated glass is far easier and less expensive to procure and install and allows for field cutting.
- It offers superior safety and security features.
- Laminated glass may be equipped with low-e glazing to help offset heat gain.
- Historic sash, both metal and wood, can be outfitted with laminated glass without modifying or replacing mullions and frame elements (something that would be required by the installation of significantly thicker IG units).
- Condensation is reduced as a result of the internal thermal break of laminated glass.
- A variety of features (UV protection, polarization, translucency, etc.) can be incorporated as layers within laminated glass. Efforts to achieve the same results in IG units through the use of applied films (as opposed to an integral layer within the glass) has been shown to greatly reduce the life of double-glazed units by inhibiting the movement of their seals.[28]

Performance and Material Quality

A hallmark of sustainability is long-term performance. Intrinsic within that premise are issues about material quality, assembly, and conservability. As noted above, some material choices (e.g., PVC) incorporated into replacement-window units are inherently not able to be conserved.[29] When the material degrades, it then becomes necessary to replace the replacement.[30]

One of the great virtues of historic windows is the quality of the wood with which they were constructed. Historic windows incorporate both hardwoods and softwoods that were often harvested from unfertilized early-growth stock. Such wood has a denser, more naturally occurring grain structure than what is generally available today from second-growth stock or fertilized tree farms. Also, historically, greater concern was given to milling methods, such as quarter- or radial sawing. The resulting window performs with greater stability than its modern counterpart. This alone has far-reaching benefits, from minimizing dimensional change, to holding a paint coating, to securing mechanical fasteners.

No amount of today's staples, glue, finger-splices, and heat welds can match the performance of traditional joinery.[31] Similar comparisons could be made of the quality of hardware employed in replacement windows, such as spring-loaded balances and plastic locking hardware; they cannot compete with the lasting performance and durability of such historic elements as pulley systems and cast-metal hardware.

Ease of Maintenance

For cleaning windows, traditional single- and double-hung windows are often outfitted with interior sash stops that may be removed readily, allowing for full access to the interior and exterior, as well as to the pulley system. Both casement and pivot windows are inherently very easy to clean inside and out.

Replacement windows incorporating tilt-in sash — a feature that on its surface appears enticing — require that there is no interior stop, increasing the potential for air infiltration around the sash. Compressible jamb liners that allow for the tilt-in feature are often constructed of open-cell foams that, once they begin to degrade, lose both their compressibility and sash-to-frame infiltration buffer.

The ability to readily disassemble historic wood windows also allows for selectively restoring, upgrading, and adapting individual components of a window throughout its life. Most replacement-window systems cannot make that claim.

Aesthetics and Authenticity

Nuances in molding profiles, shadow, line, and color of windows, along with quality and appearance of the glass, contribute greatly to the overall building aesthetic and generally emulate the stylistic details of the building as a whole. Even what might seem like small changes in these elements can and does have a noticeable and usually detrimental effect on many historic facades. Outfitting historic buildings with modern replacement windows can and often does result in a mechanical, contrived, or uniformly sterile appearance. Worse, when historic windows are replaced, authenticity is lost forever.

Value and Cost

Repairs of historic windows should add to the value of the property, as an authentically restored automobile would command greater value than one "restored" with plastic replacement parts.

While there is a dearth of cost-comparative analyses between a replacement window and its restored, authentic counterpart, empirical knowledge based on field experience covering a wide variety of window types suggests that restoration is on a par, cost-wise, with a middle-of-the-road replacement. Corollary conclusions are that:

- cheap replacement windows will always exist to superficially counter the cost-basis argument for restoration; and
- high-quality equivalent replacement units have been shown in practice to cost as much as three times that of restoration.

Windows are a critical element of sustainability, but sustainability is not just about energy. It is about making environmentally responsible choices regarding historic windows that take into account the spectrum of associated costs and effects. The choice of whether to replace or restore requires embracing a more encompassing definition of sustainability. The answer is not as simplistic as some would have us believe.

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forum journal

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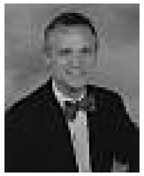
Cover photos:

Main photo: Arlene Schnitzer Concert Hall, Portland, Ore. Photo by Elizabeth Byrd Wood.

Left: Tamastslikt Cultural Institute. Photo courtesy of Tamastslikt Cultural Institute.

Center: Kam Wah Chung & Co. Museum. Photo courtesy Oregon Parks and Recreation Department.

Right: The Pearl District in Portland, Ore. Photo by Mr. Janis Miglavs, courtesy of the Portland Oregon Visitors Association.



A Defining Moment to Re-vision the American City

Earl Blumenauer

A year and a half ago I was excited about the possibility of showcasing the work that many of my friends have done to make Portland one of the most livable communities in the country, turning around a city that was really going the wrong way a third of a century ago. The National Preservation Conference would be an opportunity for people in the preservation movement to come here and kick the tires, look at what we're doing, and maybe get some ideas to help extend this movement across the country.

But then, in the last election, we had a devastating "property rights" ballot measure that puts into question the future of our land-planning process. We find that surveys still show that our citizens are committed to the goals, objectives, and outcomes of our land-use planning process, but somehow think the ballot measure won't affect that. My draft speech changed because I thought I could use your energy, vision, and commitment to help people here who are trying to contend with the consequences of the ill-defined, undefined future created by the ballot measure. And this would be relevant to all of you, because—make no mistake about it—what the forces of darkness have done here in Oregon may be coming to a town near you.

But in the course of the last month, I think all of our attention has been captured by the devastation wrought by Hurricane Katrina.

The images of destruction, misery, and chaos have laid bare issues that we've pushed aside for years. Among them, issues of race and poverty loom large. Katrina raised questions about our values, our priorities, our methodology, and our vision. What we have before us today is a defining moment in the struggle for American policies that promote livable communities.

Some people want to forget those images, hope for the best, and move on. But all the while, our oceans continue to rise, New Orleans continues to sink, and the Louisiana coastline is eroding at the rate of a football field every 30 seconds. Hurricanes Katrina and then Rita have driven home the point that there are real consequences to where and how we build.

We treat the Mississippi River as a machine, spending billions of dollars without a sense of priority, much less a vision for the future, and events have shown that in the absence of priorities and a vision for the future, spending billions does not accomplish much.

Portland, Ore., was the host city for the 2005 National Preservation Conference, where more than 2,000 preservationists from across the nation met to explore the theme Sustain America—Vision, Economics, Preservation. The impact of Hurricane Katrina and the role for preservation in recovery efforts was a major concern during the meeting. Photo by Elizabeth Byrd Wood.

A Place at the Table for Preservation

As preservationists, you have developed the language and the techniques to show people that place matters. How a community looks and feels and works depends on that sense of place. You know that historic preservation is about more than saving some old buildings. It's about knowing what to save and why it's important. You know a community's future is built on understanding its past; understanding our strengths—and even our mistakes—creates and preserves and enhances values.

What you are doing is pioneering and is of vital interest. Your skill at building unique partnerships and cost-effective strategies is what led me to you when I first went to the Congress and thought the federal government should lead by example.

We could do much to promote livable communities if the federal government modeled the behavior we expect of the rest of America. The poster child for this idea was the U.S. Post Office, which has more than 37,000 branches across America. I wanted the Post Office to obey local land-use laws and zoning codes and respect their historic structures and locations. I introduced legislation to accomplish that purpose, but I found, typically, that the National Trust was there ahead of me. We formed a vital partnership in using this issue to protect these postal resources and to get the point across. It's been a struggle to pass the bills in the post-anthrax, post-9/11 environment, especially given the vagaries of postal reform. But because of our partnership, the provisions that protect postal facilities and the rules that they play by were passed in the House a couple of months ago as part of the Postal Reform Act, H.R. 22—important landmark legislation. The National Trust played a critical role in its passage.

Some Models for New Orleans

In the aftermath of Katrina, it's time for us to think about what comes next in the rebuilding of New Orleans and other historic communities.

I know there is no shortage of ideas about what can be done now that will make a difference, including ideas from the National Trust. I deeply appreciate what the Trust has done on Capitol Hill, springing into action immediately, dealing with legislation and funding. It's making a difference.

But we need to be thinking of the other parts of the job of rebuilding.

Katrina raised questions about our values, our priorities, our methodology, and our vision. What we have before us today is a defining moment in the struggle for American policies that promote livable communities.

A very important idea has been proposed by Mercy Corps, a Portland-based emergency relief organization that usually works overseas. As a member of the Foreign Relations Committee, I visited Southeast Asia in the aftermath of the great earthquake and tsunami last year. I saw in the tsunami region that Portland-based Mercy Corps had put 20,000 Indonesians to work in a matter of days, salvaging materials that could be used for rebuilding. Here in Portland, we have a wonderful organization and facility called the ReBuilding Center, where components of homes are salvaged from demolition and reused. By recycling this material, the ReBuilding Center provides jobs, keeps materials out of landfills, and reduces our need to log trees, mine metals, and burn fossil fuels.

Mercy Corps has been in New Orleans meeting with the mayor's staff to talk about how the model of the ReBuilding Center could be used to put people to work salvaging materials from the historic structures. Even if the buildings can't be salvaged as structures, there is still no excuse to lose any of those historic building materials and artifacts. We can put thousands of people to work tomorrow, saving their heritage and making it possible for these important historic elements to be recycled. I think we ought to be smart enough to figure out how to do that in New Orleans.

Portland is home to the first modern streetcar in the United States since World War II, a priority of mine 20 years ago when I joined the city council. We've had two million people ride the Portland streetcar last year. We found developers who sold their Mercedes to ride the streetcar; they think it's a good idea. We have had approximately $1 billion of new development along the streetcar line since we broke ground; it's been integrated into the urban fabric of both the historic warehouse district and the new South Waterfront district, where cranes are raising a thicket of new housing towers beside the restored banks of the Willamette River.

The Portland streetcar was modeled after the St. Charles streetcar line in New Orleans, the oldest continuously operating streetcar in America. What if the restoration of New Orleans was built upon a grand restoration of the streetcar system? New lines could be built, extending the system into those neighborhoods that will be reconstructed. The streetcar line would spur redevelopment, provide a more balanced transportation system, and be a practical symbol of hope in keeping with that city's heritage.

Streetcars are not just of interest to New Orleans and Portland. Streetcar initiatives are underway in Charlotte, Little Rock, Memphis, Seattle, and Kenosha, Wis. Eighty-two cities have joined together in a national streetcar coalition. We were able to get a "Small Starts" provision in the last transportation bill, a provision that provides modest but important seed money for the construction of new transit systems. In the course of the last 120 years, urban America was largely built around streetcars and interurban electric systems. Let's harness that potential, build the coalition, help revitalize New Orleans, and help preservationists revitalize neighborhoods that decades ago were built around the streetcar.

The National Trust has been on the frontline, helping people understand that the historic neighborhood school is a building block of a vital community. People all over the country are now working to make sure that the billions of dollars that will be spent on school construction are spent

The St. Charles streetcar line in New Orleans, the oldest continuously operating streetcar in America, has been a model for urban mass transit in numerous American cities, including for Portland's MAX light rail system. Expanding New Orleans' streetcar system could be a key to revitalizing neighborhoods along its route. Photo: Jack Edwards, courtesy New Orleans Metropolitan Convention and Visitor's Bureau.

right, and that schools need not forsake historic neighborhoods. We shouldn't abandon structures that can be revitalized for a fraction of the cost of new development, which chews up land and greenfields needlessly, when we can revitalize existing neighborhoods. Let's make the pioneering work that you and others are doing around the country part of the federal effort to revitalize New Orleans and the other affected communities in the region.

Cautions and Warnings

I could go on and on with great ideas, and so could you. But we need to stop, catch our breath, and think about how we're going to make it possible for this tremendous outpouring of concern and energy and money to be used right.

First, I think the federal government needs to establish its own principles of partnership for Katrina, both for the recovery and for incorporating the lessons learned, as well as the lessons that we should have learned.

- The federal government must not use taxpayer money to put people, places, and property back into harm's way.
- Citizens should be directly engaged in the work of disaster recovery and mitigation at every step of the way.
- Anybody who has watched television, listened to National Public Radio, or read any of the international press knows that we have to clarify the role of the federal government in disaster prevention, mitigation, and relief, starting with making FEMA functional again.
- We must make the recovery process the model of transparency and of accountability.
- Congress should also encourage, support, nudge—and in some cases demand—state and local responsibility for disaster prevention, mitigation, and recovery. Local governments do their citizens no favors by having lax building codes and zoning regulations that put their citizens in harm's way.
- The gusher of federal funds for restoration must be carefully invested in ways that incorporate disaster prevention, community preservation, and mitigation as key elements.
- And last, but by no means least, we should make sure that wherever possible we harness the power of nature to defend against the forces of nature. One practical way to do this would be to create a public space from land that shouldn't be redeveloped: wetlands that used to provide an important natural buffer for New Orleans. What better way to honor the victims of Katrina than to dedicate these wetlands as a memorial that will protect people in the future?

One thing I have learned during my 30 years in government is the limit of government power. The federal government is not equipped to dictate the terms of what goes back in those communities; establish principles, yes, but not to manage and direct the construction. Politicians need help in managing the inevitable pressures of recovery efforts.

You know too well that today's political process is toxic and hopelessly partisan. We also have to talk about the elephant in the room that people don't want to mention: corruption.

There are issues of integrity and responsibility and transparency that must be addressed, but it must be your crusade. You must hold elected leaders accountable and get us to focus on the big picture and the long term.

A Unique Opportunity for Re-visioning

You could help carry out an idea I've been mulling over: the world's largest community planning event, drawing on some of the best minds and the most creative thinkers to discuss how New Orleans and all the communities in the Gulf could be rebuilt in ways that make them more livable, more economically secure, and safer in their natural settings. I've talked to numerous people who could be potential partners with the National Trust in this project about how we could involve a wide range of people through teleconferencing and C-Span broadcasting. We could have an opportunity for people in the affected area to log-in online and ask questions.

There is a coalition of the committed and the capable that could do this; it would benefit both the politicians and citizens. It would provide an opportunity for Americans to get the big picture, to help us see how this unfolds, to understand what's possible—because we have only a moment. If we don't act quickly, we will lose precious historic resources as well as the ability to resist the growing pressure to demolish the damaged structures we have left. We have a very narrow window before we lose our chance to act.

The Great London Fire of 1666 brought forth some fascinating designs for redevelopment. Within days of the fire, the esteemed architect Christopher Wren drew up a vision of a greater London—but the moment passed and the opportunity to redesign London was lost. After the rebuilding, London was better, more fire resistant, but the chance to make it an even finer city escaped. We should not allow that to happen now.

Regional visioning processes often fail for a lack of money to implement the results; they fail because we can't get other regional partners to the table; they fail because the federal, state, and local governments won't cooperate; they fail because there's no sense of urgency. Well, let me tell you, none of these criteria apply in the area hit by Katrina. You've got people's attention, it is urgent, and there will be money—amazing amounts of money.

For comparison purposes, the estimated value of all the urban development in the entire Portland metropolitan area—a region that has a slightly bigger population than New Orleans—is $148 billion. That is a lot of money

This is an opportunity to seize the moment that I bet all of you felt after 9/11. This is a chance to bring the country together, to unify, to have a government of unity, and to give people assignments and march forward.

to be sure, but less than the $200 to $300 billion in federal disaster relief currently being discussed in Washington. The amount of money is staggering and the potential of doing things with it—good or bad—is beyond belief.

But it's not just about restoring the Gulf Region and getting those people back on their feet. I'm of the opinion that this is an opportunity for us to change the way that Washington operates. This is an opportunity to seize the moment that I bet all of you felt after 9/11. This is a chance to bring the country together, to unify, to have a government of unity, and to give people assignments and march forward. We didn't quite do that after 9/11, but I think we've got a chance to do it now. Your good work, your willingness to be a part of this process, will not just make a difference for those people who have lost their homes and their communities. I'm convinced that it is an opportunity to heal the body politic as well.

I leave with you with a quotation from Isaiah chapter 58:12. The prophet Isaiah is talking about the destruction of Jerusalem at the hands of the Babylonians:

Those from among you shall build up the old waste places;
You shall rise up the foundations of many generations;
And you shall be called the Repairer of the Breach;
The Restorer of Streets to Dwell In.

Congressman Earl Blumenauer has devoted his entire career to public service. First elected to the Oregon House of Representatives in 1972, he served on Portland's city council and has represented Oregon's Third Congressional District since 1996.

Editor's note: On October 14, 2005, Oregon's Measure 37 land-use law was overturned by a county circuit court judge. This controversial measure, approved by 61 percent of the voters in November 2004, gave property owners the right to develop their property under the rules and regulations in effect at the time they acquired it, without regard for the community planning rules their neighbors live by. The judge ruled the measure unconstitutional because it favored longtime property owners over those who had purchased property more recently, and because it prohibited the Oregon legislature from exercising its authority to regulate for public welfare, health, or safety. Measure 37 opponents are now preparing to fight an appeal made to the Oregon Supreme Court, which will be heard January 10 in an expedited schedule.

The National Park Service and Its Partners Taking Action in the Gulf Coast and Around the County

Fran P. Mainella

Let me begin with my own heartfelt sympathy for the victims of the storms that have so recently swept through the South. Above all, the personal tragedies of our fellow citizens require our support and our understanding. I spent much my life in Florida and have seen the power of these storms first hand—but nothing that matches the scale of damage that has just struck some of our most treasured historic places.

From southeastern Louisiana to Mobile Bay, Hurricane Katrina damaged some of the historic legacy of more than 300 years of American history. The Gulf Coast has long been recognized for its unique blend of French Creole, Anglo-American, and African-American cultures, and the Creole influences that predominated during the 18th and 19th centuries played a central role in creating some of the most distinctive architecture in North America.

While it likely will be months before the full extent of the damage is known, it is clear that the storm took a heavy toll on the heritage and historic fabric of the Gulf Coast. There is a little bit of good news, however: The most historic parts of New Orleans, especially the famed French Quarter and nearby Garden District, escaped largely unscathed.

The National Park Service is working on restoring much of the impacted areas, including many sites listed in the National Register. In neighborhoods such as the Esplanade Ridge Historic District, which encompasses nearly 1,500 examples of Creole-style domestic architecture, there was extensive flooding. The Creole cottages, shotgun houses, and raised villa-style residences found in Esplanade Ridge and throughout the city are mainly wood-frame structures built on piers, which are especially susceptible to water infiltration.

Flooding also damaged sites such as Congo Square, also a site of great interest to the National Park Service and the preservation community. Congo Square was historically the main gathering place for free and enslaved blacks. Even before the Civil War, African-Americans gathered here to keep alive their African heritage through dance, music, handicrafts, and to socialize. Restoring this site is one of our priorities. Dillard University, a historically black institution with elegant Classical Revival–style buildings, in the past has received NPS preservation grant funding. This site also was struck by wind damage and flooding.

The museum collections of Jean Lafitte and New Orleans Jazz national parks were held in a building that, thankfully, was spared. We have moved their museum collections temporarily to Natchez, Miss., because essential climate control will not be possible for some weeks—until utility services are restored. On the ground, Chalmette Battlefield, site of the famous Battle of New Orleans, was pretty badly damaged also. But we are confident much of the landscape will recover, given time. Artillery pieces have been removed from the battlefield and sent to Springfield Armory National Historic Site in Massachusetts for whatever maintenance or repair proves needed. The Chalmette National Cemetery suffered some damage from uprooted trees, which exposed cultural artifacts, including human remains. These have been placed in appropriate storage until they can be suitably returned.

In Mississippi, the museum at the Gulf Islands National Seashore was heavily damaged, so we have moved most of the collection to our Southeast Archeological Center for recovery or Timucuan Preserve in Jacksonville for storage. Sadly, of course, the Florida end of the Gulf Islands is still recovering from last year's devastating hurricanes, so the same facilities are already housing collections from those events. We can rebuild where we have good records of what was there. We have good photographs and plans and other drawings of many of the places that we care about. We will be able to pass on this record of lives and achievements to posterity, even after a destructive event like Hurricane Katrina.

The Historic American Buildings Survey and Historic American Engineering Record have documentation on more than 800 sites in the Gulf Coast areas affected by Katrina. Following Hurricane Katrina, staff in the cultural resources programs of the National Park Service have responded with guidance on recovery and stabilization of sites, structures, and objects in the impacted areas. We have provided extensive site documentation, technical information, and training; developed new tools specifically to meet the needs of the states; and provided limited onsite assistance.

Hurricane Rita was less powerful than Katrina and less harmful to park resources; however, again, some National Register properties have been affected—especially in the region surrounding Port Arthur, Tex., and Lake Charles, La. The NPS parks suffered downed trees, lost utility services, and minor building damage to public-use facilities in Big Thicket National Preserve, Cane River Creole National Historical Park, and even Vicksburg National Military Park.

We have long talked of the value of strong partnerships. It is these types of crises that test the strength of these partnerships. And they are holding strong! We are very proud of what we have been able to do in the wake of Katrina and Rita, but we've learned valuable lessons of what we and others can do differently—and better. We remain concerned that singular resources be saved, wherever it makes sense, in the aftermath of an event like this. Part of our job is to teach those who must be focused on short-term solutions to massive problems, so that they recognize that preservation makes sense!

Other Important Work of NPS and Its Partners

In late September we testified in support of re-authorizing the Advisory Council on Historic Preservation and the Historic Preservation Fund. Let me just take a minute to say we want both back, and stronger than ever! We are working closely with the

Recently approved to become a National Historic Landmark, the Kam Wah Chung & Co. Museum in John Day, Ore., is a remarkable survivor that offers a glimpse into the life and culture of the early Chinese community in eastern Oregon. Constructed in 1875 as a trading post, it also evolved over the years to become a social, medical, and religious center. Photo: Courtesy Oregon Parks and Recreation Department.

The Kam Wah Chung & Co. Museum houses a vast collection of artifacts, including business and financial records, posters, advertisements, supplies, and Chinese herbs and medicines. The National Trust has awarded the Oregon State Parks a $7,500 grant to help fund a professional assessment of curatorial needs and develop in-place treatments for these artifacts.

ACHP on a number of important initiatives, including the Preserve America program and compliance tools. We value that partnership.

Also on a positive note, over the years, the Historic Preservation Fund has been a highly flexible authority for developing targeted grant programs that address the broad purposes of the National Historic Preservation Act. They include the grants to Indian tribes to support Tribal Historic Preservation Offices and project grants to preserve America's native cultures; grants to Historically Black Colleges and Universities to preserve significant campus buildings; the Save America's Treasures grant program for threatened nationally significant properties; and more recently, the Preserve America grant program for heritage tourism, including education and economic revitalization.

These grant programs not only preserve historic resources, they attract new economic investment. We have asked Congress to renew the fund for another 10 years.

We also take great pride in our recognition programs. Our highest recognition standard remains the National Historic Landmark. Earlier this month, the National Park System Advisory Board recommended National Historic Landmark designation for 13 properties. Secretary of the Interior Gale Norton has already acted to approve the first of that group—the Kam Wah Chung & Co. building in John Day, Ore. The building is important for its association with Chinese immigrants in the development of the American West, when the Chinese came to the West to work in mining, on the railroads, in the lumber industry, in the construction of wagon roads, and in agricultural jobs. It is one of the finest representatives of the Chinese role in the post–Civil War expansion period of the American West and the sole remainder of the town's once-thriving Chinese community.

Through the work of our partners in the states, we can cite significant achievements over the past year: The National Park Service approved 1,537 new listings, which include 46,619 properties, in the National Register of Historic Places. The Historic Preservation Tax Incentives program resulted in the rehabilitation of more than 1,200 historic properties listed in the National Register, creating some 15,000 new housing units, and generating $3.8 billion in leveraged private investment.

In FY 2005, the Save America's Treasures grant program awarded a total of 145 matching grants in 43 states and the District of Columbia totaling $29.5 million. Our partners in the program are the National Endowment for the Arts, the National Endowment for the Humanities, and the Institute of Museum and Library Services.

We—the National Trust, the Advisory Council, and the Park Service—can provide guidance, inspiration, and even some financial stimulus. But the day-to-day work of identifying needs, conceiving solutions, and rallying essential support for special projects, structures, and events is a task we share with those who care—the deeply dedicated grassroots workers in cities and towns across America.

We're fortunate to have so many partners already active in historic preservation. Now, more than ever, we must convert the passion to action…and the possibilities to realities.

Fran P. Mainella is the director of the National Park Service.

NPS Response to 2005 Hurricanes Updated November 22, 2005

National Park Service employees continue to feel the effects of the hurricane season well into November as they try to restore a sense of normalcy to their lives and those affected by these devastating hurricanes. Many employees still are working from temporary buildings and office spaces and are dealing with lost homes and property. Contractors are working to stabilize buildings and repair roofs on government structures. Recreational opportunities have been canceled or reduced to accommodate the loss of management facilities and staff. Many parks that had already expe-

rienced difficult budget projections are now scrambling to reassess important priorities and decide what buildings can be repaired, replaced, or left as is.

Under the National Response Plan, the Department of the Interior is the lead agency for the Natural and Cultural Resources and Historic Properties Protection part of Emergency Support Function #11. Following Hurricane Katrina, the National Park Service cultural resources programs responded by providing documentation, technical information, and assistance services in collaboration with other federal and nonfederal partners. The Park Service rapidly designed detailed building and site condition assessment forms, posted data on the internet concerning National Register listings in the impacted areas, provided maps of impacted National Register historic districts, and data on individually listed sites to the Mississippi and Louisiana state historic preservation offices. This information helped to facilitate decisions regarding preservation and protection of districts from immediate demolition. Park Service cultural resources employees provided training to 110 professionals in the impacted areas, established a website to provide technical information on recovery and preservation of cultural resources (www.nps.gov/katrina), and worked with Louisiana Public Broadcasting to air a public service announcement about the preservation of cultural heritage. Park Service teams assisted affected parks and more than 80 cultural resources employees volunteered their services and stand ready to respond to FEMA requests for assistance. To date, 16 National Park Service cultural resources employees help make up two federal teams assigned to assist FEMA at headquarters and the Louisiana and Mississippi Joint Field Offices. In addition, three Park Service planners are helping FEMA address local community long-term recovery planning issues in Mississippi.

The Power of Stories and Memories

David Mas Masumoto

I wrote a book about a peach, a very special peach, that I think has historical significance in the sense that it talks about the power of story. First let me describe this peach that I grow.

Sun Crest is one of the last remaining truly juicy peaches. When you wash that treasure under a stream of cooling water your fingertips instinctively search for that gooshy side of the fruit. Your mouth waters in anticipation. You lean over the sink to make sure you don't drip on yourself, and then you sink your teeth into the flesh and the juice trickles down your cheeks and dangles on your chin. This is a real bite, a primal act, a magical sensory celebration announcing summer has arrived. (from Epitaph for a Peach*)*

That's the kind of peach that I grow, but it has two problems. When the peach is ripe, it has an amber glow to it. It's not lipstick red like many other peaches have been bred to be. Also, it doesn't have so-called shelf life. It won't stay on a grocer's shelf for a year.

I've been told that this peach has no mass-market appeal, it can't compete, it's outdated, it's old, it's better that you plant new varieties. I've been told there is no audience for it, you'll never make lots of money farming it. You're eternally working with something old and something claimed to be obsolete.

I wonder if old peaches and the preservation of historic places have something in common.

My quest was to find a home for this homeless peach, and that led me to continue to farm it. It also led me to write some books about it too. But the books are not just about how to sustain a family farm. They are also about sustaining meanings that support great taste, and I think it's similar to the work of preserving and sustaining America. And my question for you would be, how do you grow sustainable places? And my answer is, through the power of stories and memories.

Every year I have a quest to grow the perfect peach. It's a quest to find that peach that will be timeless and priceless.

My question for you would be, how do you grow sustainable places? And my answer is, through the power of stories and memories.

It's a perfect peach that has a story, and I'll describe to you something that I found when I was close, when I almost found that perfect peach.

My grandma taught me how to eat a peach. She'd sit on a small wooden stool and slice peaches, and occasionally she'd stop and like an innocent child she'd steal the taste of the golden flesh and quickly sneak a piece into her mouth. I watched her close her eyes and they seemed to tremble, muscles of an 80-year-old involuntarily twitching and dancing as if lost in a dream. My grandmother savored the flavor. A satisfying glow gently spread across her face, not a smile or even a grin, just a look of comfort, relaxed, soothing, content.

I thought of that image even after she died, wanting to believe that would be the look on her face forever. My grandmother and I shared a perfect moment and I've spent years trying to reenact the same closing of my eyes, smacking my lips. I smile and gradually lose myself in the flavor of a perfect peach memory. (from Four Seasons in Five Senses*)*

I think it is memories that we are after. When you combine memories with the power of story it makes things significant, because only when memories and stories go public do they gain significance.

A perfect memory to me is one that is a community memory. Farmers and those who are engaged in historic preservation, we grow stories, but our stories must be taken in context over time. In other words, history counts because stories without history are like sound bites. Stories without history are like the flavor of a peach with no taste. You eat one and five minutes later you can't remember what you ate. We face challenges, however, when we deal with truth-telling because that's what good stories are all about.

Truth-telling often taxes us, and I believe that it's important that we keep a lighter side to our work in mind, a lighter side that reminds us what it is to be human. In working to save this old peach variety, I've found that I discovered life that came back to my farm.

That's the power of story and the power of memory. The challenge for us is to sustain our stories.

Let me share three elements of sustainable farming that maybe will have parallels with your work. The three elements are farming that is environmentally responsible, farming that is socially just, and farming that is economically viable. Perhaps that's similar to the conference theme of vision, economics, and preservation.

First, sustainable farming that's environmentally responsible. On my farm peaches are part of a place. I have the responsibility to take care of that place. You might say the history of my peaches must take place somewhere. I hope by becoming a steward of the land that I can continue to grow great peaches, and that's why I farm it organically, because I partner with nature on my land.

The common bond that we share in this room is that your work takes place in real places.

These are places with stories, just as a farm is more than just dirt, and history is more than dates and names. We work with a sense of place, and it's all about taking care of those places. Organic farmers work with endangered species, preservationists work with endangered places, but we also work with endangered stories.

Organic farmers work with endangered species, preservationists work with endangered places, but we also work with endangered stories.

The second part of sustainable and organic farming for me is that it's socially just. The perfect peach is not just grown organically. It has to be grown with the realization that there are communities and workers around me.

My work is inclusive, not exclusive. It includes the human element, the human capital. There's a human story behind my peaches. It's a story that's part of the memory of a great peach, because when you work on a farm, especially a family farm, you include generations on the land. It's part of that sense of place.

These are stories that are not necessarily pleasant, and I'll paraphrase one story from *Harvest Son* where I wrote about how our farm began. After World War II my dad took the gamble and bought some farmland, and my grandmother became furious with him and she said, you should not have bought land because in America they take it away. It's part of that simple story of a farm that adds that human character, that human dimension to the land.

Third, sustainable farming is economically viable. This is probably the hardest thing, yet the simplest lesson for myself when it dawned on me that going bankrupt and not growing wonderful tasting peaches does no one any good. Yet part of my job in my work faces this reality: What I do best will not always make the most money. It was a hard reality for me to understand and realize that, like for you, my farm is nonprofit.

But here's how I hope to be economically sustainable. My work is not about making money, but it is about making stories. I farm stories that make money, and that's at the heart of each peach that I grow. My peaches fill the flavor niche that industry left behind.

Large-scale farming operations can't mimic my methods, in which skill and human management replace huge doses of capital and technology. I want my fruits to manifest the life and spirit of our farm. Mass-produced peaches are designed to excite only the visual sense as consumers trade money for something that resembles a peach.

My peaches begin a journey into taste, texture, aroma accompanied by stories. People who enjoy my peaches understand and appreciate flavor. They pay *attention to memories and stories. (from* Four Seasons in Five Senses*)*

Our challenge is to foster and build memory, and the biggest concern that I have as a grower is to make sure that people get to taste a wonderful peach, because how can you miss something if you've never experienced it.

[As part of his presentation, Masumoto demonstrated "How Farmers Eat a Peach" with samples of organic peach jam from his family farm. He shared this with the audience—a literal and figurative "taste" of how the perfect peach memory transports us and a demonstration of the power of memories and stories.]

Let me end with one final passage from *Letters to the Valley*, which is one of my latest books. This book is written as letters, and this last one is called "Hunger for Memory," and it's a letter written to my father.

Dear Dad, you taught me how to have a hunger for memory, not nostalgia and a longing for the past that can never begin again, but a memory that's alive with passion and excellence. Our family farm was never about trying to make big piles of money.

Instead, you instilled a desire to create a memory of something great and a passion to rediscover it each summer. I inherited your quest to keep that flavor ripening each year. Dad, I think of your life's work as a priceless gift you passed on to another generation, a different sort of legacy that parents hope to leave behind neither in wealth nor land, but a portfolio of stories.

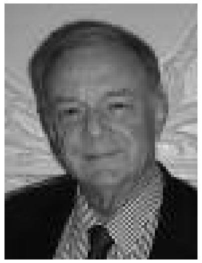
Dad, without knowing it you taught me a lesson about how to save our farm. When we work as artisan farmers we excite consumers with stories of passion. It's okay to dream of perfection. The memory of a perfect food moment can become our greatest tool.

We all should hunger for memory.

David Mas Masumoto is a writer, a columnist for the Fresno Bee, *and an organic peach and grape farmer. Reprinted with permission. Copyright 2006, David Mas Masumoto.*

"Property Rights" for All: An Issue of Social Justice

David Rusk



New Orleans: Unveiling "Hidden" Poverty

In the past month we have all witnessed a massive assault by Hurricane Katrina on New Orleans, one of the country's great historic treasures. Most of us are both anguished by a sense of loss and challenged by what must be done to retrieve what we can.

I know New Orleans well. In 1999 I conducted a year-long study of the New Orleans region. My study was co-sponsored by three dozen organizations ranging from the New Orleans Regional Chamber of Commerce to the Preservation Resource Center of New Orleans to a half-dozen city community development corporations. Two key leaders were Pres Kabacoff, head of Historic Restoration, Inc., a superb urban redeveloper who pioneered the rebirth of New Orleans' trendy warehouse district; and Bill Borah, a local attorney and leader of the preservation movement who had won "the Second Battle of New Orleans" two decades earlier, stopping plans to build an interstate highway through the French Quarter.

My study yielded three principal findings:

1. There was no semblance of anti-sprawl land-use planning throughout the region. Over the past five decades urbanized land expanded at three times the rate of growth of urbanized population. New Orleans was the largest American city without a master plan; the political culture promoted "planning" deal-by-deal. Built-out scenarios of suburban St. Tammany, St. Bernard, and St. Charles parishes estimated that they were zoned for three to four times their current population—to the extent that zoning existed at all. State government must mandate strong, anti-sprawl land-use planning (a highly improbably event politically in Louisiana, a state that seemed to welcome new development on any terms).

2. Most stunningly, sprawl had been almost a zero-sum game. Adjusted for inflation,

the growth of assessed valuation (property wealth) between 1950 and 1998 had been only 16 percent for the entire six-parish region. Only 16 percent in 48 years! New property wealth created in suburban parishes was largely offset by a decline of older property wealth within New Orleans, which had lost more than half of its tax base (56 percent). Did Katrina destroy more than half of the city's remaining property tax base in 48 hours, as suburban sprawl and urban disinvestment had in 48 years? I doubt it.

3. Concentrated poverty was overwhelming the city's assets. Among this country's major cities, New Orleans had the second highest poverty rate (only behind Detroit's). In 1990, out of 176 census tracts in New Orleans, the poverty rate exceeded 20 percent in 121 tracts; the poverty rate fell between 41 percent and 60 percent in 42 tracts and exceeded 61 percent in an astounding 17 tracts (each of which had one of New Orleans' 10 massive public housing projects located in or adjacent to it). To attack concentrated poverty, a) the region's economic growth must be accelerated,[1] and b) specific housing policies must be adopted to mainstream the black poor through federal HOPE VI programs and regional inclusionary zoning policies.

In short, the New Orleans region was a classic example of "spreading our wealth while concentrating our poverty."

My report, *The New Regionalism: Planning Together to Reshape New Orleans' Future*, was published as a 20-page tabloid insert by the *Times-Picayune* (circulation: 287,000) and another 30,000 copies were distributed through other outlets. I presented my report in a public lecture attended by more than 500 civic leaders sponsored by the University of New Orleans, my research partner.

And then … very little happened. Confronted with how hard it was to change basic "rules of the game" that, while they may afflict the weak, reward the powerful, the coalition of community groups steadily dissolved.

One step, however, was taken. Pres Kabacoff's company took over the troubled HOPE VI process to completely re-create the massive St. Thomas public housing project as a mixed-use, mixed-income neighborhood. St. Thomas is located in the Lower Garden District about two blocks south of the re-gentrifying Magazine Street. "River Garden" would be New Orleans' first HOPE VI redevelopment and, with a mix of about 30 percent public housing and 70 percent market-rate housing, would be New Orleans' first experiment with mixing middle-class and public-housing households.

Analyzing the market, Pres decided that he needed a flow of revenue from onsite retail businesses into the overall development in order to further reduce apartment rentals to levels that would surely be attractive to middle-class tenants. As an anchor store, he signed up Wal-Mart. "Pres," I told him, "Wal-Mart is the *bête noir* of the preservation movement nationwide. Couldn't you have found even a Target or K-Mart instead of a Wal-Mart?"

Led by my friend Bill Borah, the local historic preservation movement fought the Wal-Mart tooth and claw before the city council and in the courts. (The National Trust for Historic Preservation itself actually intervened in opposition to the Wal-Mart.) I was receiving calls, articles, and e-mails from both sides.

My view was that the greatest enemy of historic preservation in New Orleans was not Wal-Mart but concentrated poverty that sapped the vitality and value of so many historic neighborhoods. I wrote an op-ed piece for the *Times-Picayune* making that point and urging the preservation movement to become vocal champions of inclusionary zoning and other mixed-income housing development strategies in both the city and its suburbs.

At one point, I heard that some opponents argued (though not Bill Borah) that if rental income from Wal-Mart was needed to offer more attractive rents for middle-income tenants, just drop Wal-Mart and build River Garden entirely for public housing families. If true, I find that proposition totally repugnant and immoral.

River Garden has gone forward and (with a somewhat scaled down Wal-Mart store) is reported by the *Times-Picayune* to be a great success—with the Wal-Marts having minimal or no impact on the prosperity of specialty-retail Magazine Street.

To our national shame, Hurricane Katrina ripped the veil off the "hidden" problem of poverty in New Orleans and the Gulf Coast—a problem "hidden" only from eyes that were determined not to see. Whenever a hard line is drawn between historic preservation on the one hand and advancing economic opportunity and racial justice on the other, I'm always going to be on the side of justice.

Measure 37 and Other Inequities

We are meeting in Portland, Ore., where another type of hurricane—Measure 37, the so-called "property rights" amendment—has ripped across the public policy landscape, threatening to undo more than 30 years of the nation's most sensible comprehensive land-use planning.

The so-called "property rights" movement seems always to be concerned with the rights of "greenfields" property owners on the metropolitan periphery. It must have occurred to some of you to ask, "what about the property rights of all those property owners whose property values vanished while sprawl was costing New Orleans over half its tax base?"

We need to re-define the property rights issue to assert *everybody's* property rights—not just those of the relatively favored few.

Let's not talk further about New Orleans that, post-Katrina, may be a special case. Let's look at the Detroit region with a central city even poorer than New Orleans.

Under the provisions of Michigan law, the three counties around the city of Detroit (Macomb, Oakland, and Wayne) have long been totally divided up into 131 municipalities. State law delegates "comprehensive" planning and zoning powers to these 131 "little boxes" (that average about 14 square miles each), setting no regional planning goals nor even requiring that each "little box" consider the effect of its development actions on its neighbors. The rule is "every jurisdiction for itself and the Devil take the hindmost." Well, the hindmost is always the city of Detroit.

From 1970 to 2000, even though this three-county area lost population, it did see net formation of 283,000 households. However, within the state of Michigan's "every-'little-box'-for-itself/Devil-take-the-hindmost" system (powerfully subsidized by sprawl-favoring, state-controlled highway and other infrastructure spending) area homebuilders constructed 584,000 new housing units—more than twice as many new homes as there were new households to fill them. The new always sells and the new always rents, but the region's "hindmosts" saw 270,000 older housing units just vanish—rendered economically valueless by excess housing supply. Many wonderful, historic structures and traditional neighborhoods disappeared. (The City of Detroit owns 44,000 vacant lots where homes once stood.) Overall, in the last 44 years, Detroit has lost 71 percent of its property tax base!

That's not just a bloodless statistic. Each of those 270,000 vanished houses was once some family's most valued asset—most often, some African-American family's most valued asset. Across the country the greatest intergenerational transfer of wealth in history is occurring right now as the Greatest Generation transfers its accumulated home equity to the Baby Boom generation, and Generation X is poised to inherit that wealth in turn from their parents and grandparents—if they are white. Because of the destruction of housing values experienced by most African-Americans, their heirs will inherit nothing but debt.

In Michigan (as in many states), state law sets up one class of favored property owners (periphery property owners) at the expense of other property owners (core-area property owners).

I am not a lawyer, but that sounds to me like a state's denying "equal protection of the laws" under the XIV Amendment to the United States Constitution. My colleagues Myron Orfield and John Powell are lawyers. We are collaborating on researching a class action suit in an appropriate federal court to focus on the destruction of these urban dwellers' property rights by the very policies championed by so-called "property rights" advocates.

The Need for New Coalitions

Why take this issue on? We are taking this on because, for example, Measure 37's electoral success in Oregon is no instance of the "little people" spontaneously rising up against "Big Government" bureaucratic tyranny. It is rather the fruit of a carefully orchestrated campaign by radical ultra-conservatives, spearheaded intellectually by libertarian think tanks such as The Heritage Foundation, Cato Institute, and the chain of state little Cato Institutes, litigated by libertarian groups like Defenders of Property Rights and Mountain States Legal Foundation, and fueled by tens of millions of dollars from oil companies, highway contractors, homebuilders associations, forest industry and mining giants, and auto and bus manufacturers.

We are all targets—growth management advocates, New Urbanists, historic preservationists, organizers of poor communities such as ACORN, faith-based coalitions committed to social justice, progressive labor unions. Whatever our specific cause, we share a common ethos: serving the common good, asserting the value of responsibility to a larger community.

For all the populist-appealing rhetoric of property rights advocates (well-honed by focus groups), their brand of rampant, unfettered "free market" individualism ends up apportioning the lion's share of benefits to the richest and most powerful.

Too often we "good guys" are feuding amongst ourselves, working at cross purposes. Our house, divided against ourselves, cannot prevail.

I challenge the members of the National Trust for Historic Preservation to rethink some of your goals, to take a fresh look at the limited range of your alliances. You've done so before about 15 years ago, broadening your focus from just historic buildings to entire historic neighborhoods. You need to reframe your mission within the context of regional economies and increasingly unjust and inequitable social trends.

Let me rephrase an observation by a Holocaust survivor, reflecting on what happened in Nazi Germany in the 1930s.

First, they came after organized labor, but I did not speak out for I am not labor;
then they came after the poor, but I did not speak out for I am not poor;
then they came after regional Smart Growth advocates, but I did not speak out for my focus is some buildings and some neighborhoods;
then they came after the New Urbanists, but I did not speak out for I am into Old Urbanism;
and then I realized, when they come after me, there will be no one left to speak out for me.

David Rusk has spoken and consulted on urban policy in more than 120 metropolitan areas. A former mayor of Albuquerque, New Mexico legislator, and federal official, he is author of Cities Without Suburbs, Baltimore Unbound, *and* Inside Game/Outside Game.

NOTES

[1] Compared to its nine peer regions, New Orleans ranked only ahead of Birmingham in job growth (1950-97), had the highest regional poverty rate in 1990, and the slowest growth in median family income (1950 to 1990).

Editor's note: On October 14, 2005, Oregon's Measure 37 land-use law was overturned by a county circuit court judge. This controversial measure, approved by 61 percent of the voters in November 2004, gave property owners the right to develop their property under the rules and regulations in effect at the time they acquired it, without regard for the community planning rules their neighbors live by. The judge ruled the measure unconstitutional because it favored longtime property owners over those who had purchased property more recently, and because it prohibited the Oregon legislature from exercising its authority to regulate for public welfare, health, or safety. Measure 37 opponents are now preparing to fight an appeal made to the Oregon Supreme Court, which will be heard January 10 in an expedited schedule.

Economics, Sustainability, and Historic Preservation

Donovan D. Rypkema

As we've heard all week, the theme of this conference is *Sustain America: Vision, Economics, and Preservation.* So I'd like to expand the vision of the relationship among those things—economics, sustainability, and preservation.

In 2004 I attended the World Urban Forum in Barcelona. The World Urban Forum is UN Habitat's biennial gathering of people from around the world who are dealing with issues of cities.

In Barcelona there were 5,000 people from 150 countries. During the week, there were 300 sessions—workshops, plenary addresses, panel discussions—and thousands of less-formal interactions. Not surprisingly, the most commonly heard phrase was *sustainable development.* But you know what the second most common phrase was? *Heritage conservation.* There were perhaps a dozen sessions specifically about historic preservation, so hearing the phrase there was no surprise. But *heritage conservation* permeated the sessions that on the surface weren't about historic preservation at all—sessions about economic competitiveness, job creation, housing, public-private partnerships, social cohesion.

Much of the world has begun to recognize the interrelationship and the interdependency between sustainable development and heritage conservation.

Much of the world, but much less so in the United States. With one notable exception, I'm not so sure we've really connected the dots. Too many advocates too narrowly define what constitutes sustainable development. Let me give you an example.

Over a year ago in Boulder, Colo., a homeowner in a local historic district applied to paint his window sash and trim, and approval was given the same day. Two weeks later the landmarks commission learned that the historic windows had all been removed—a clear violation of the local ordinance—and had been replaced with new windows. This was done by a contractor who claims to specialize in "ecologically sound methods" and bills himself as "Boulder's greenest contractor."

The landmarks commission sent a letter directing that the original windows be retained and their condition documented. The contractor responded saying that the greater energy efficiency of the new windows should outweigh the regulations that apply to houses within the historic district. A subsequent commission hearing upheld the staff position and a city council hearing supported the commission's ruling.

Here's the next chapter—a reporter for the local alternative newspaper decided to take matters into his own hands. He went to the house, picked up the historic windows, took a sledgehammer to them, hauled them to the dump, and arranged to have a bulldozer run over them. Sort of a 10-year-old's version of civil disobedience.

Now I want to stop the story for just a minute. I'm not necessarily sure that the landmarks commission's decision was right. But I'm telling you the story to demonstrate our ignorance about what sustainable development really is.

First from an environmental perspective:

1. The vast majority of heat loss in homes is through the attic or uninsulated walls, not windows.

2. Adding just three and one-half inches of fiberglass insulation in the attic has three times the R factor impact as replacing a single pane window with no storm window with the most energy efficient window.

3. Properly repaired historic windows have an R factor nearly indistinguishable from new, so-called "weatherized" windows.

4. Regardless of the manufacturers' "lifetime warranties," 30 percent of the windows being replaced each year are less than 10 years old.

5. One Indiana study showed that the payback period through energy savings by replacing historic wood windows is 400 years.

6. The Boulder house was built more than a hundred years ago, meaning those windows were built from hardwood timber from old growth forests. Environmentalists go nuts about cutting down trees in old growth forests, but what's the difference? Destroying those windows represents the destruction of the same scarce resource.

7. Finally, the diesel fuel to power the bulldozer consumed more fossil fuel than would be saved over the lifetime of the replacement windows.

The point is this: Sustainable development is about, but not only about, environmental sustainability.

• Repairing and rebuilding the historic windows would have meant the dollars were spent locally instead of at a distant manufacturing plant. That's economic sustainability, also part of sustainable development.

• Maintaining the original fabric is maintaining the character of the historic neighborhood. That's cultural sustainability, also part of sustainable development.

Most of you know of the LEED certification system of the U.S. Green Building Council. Currently circulating is a draft of a proposed rating system for neighborhood developments. To its credit, the council assigned weight for adaptively reusing a historic building—up to 2 points…out of 114. Well, at least it's a step in the right direction.

But if we don't yet "get it" in the United States, others do. King Sturge—an international real estate consulting firm headquartered in England—has been at the forefront of broadening the concept of sustainable development. The firm's framework for sustainable development certainly includes environmental responsibility but also economic responsibility and social responsibility. I'm going to take the liberty of expanding the third category into social and cultural responsibility.

The firm further identifies these important nexus: For a community to be viable there needs to be a link between environmental responsibility and economic responsibility; for a community to be livable there needs to be a link between environmental responsibility and social responsibility; and for a community to be equitable there needs to be a link between economic responsibility and social responsibility.

When we think about sustainable development in this broader context, the entire equation changes—and includes more than simply asking, "Is this building LEED certified?" or "Is the snail darter habitat being protected?"

When we think about sustainable development in this broader context, the role of historic preservation becomes all the more clear.

Environmental Responsibility

How does historic preservation contribute to the

In downtown neighborhoods across the country, such as Portland, Ore.'s trendy Pearl District, a new generation of restaurants, shops, and small businesses are making good use of historic commercial buildings. Photo by Mr. Janis Miglavs, courtesy of the Portland Oregon Visitors Association.

The United States faces a shortage of affordable housing. Yet older residential buildings are being razed at an alarming rate—wasting their "embodied energy" as well as their potential to meet community housing needs. Photo by Donovan D. Rypkema.

environmental responsibility component of sustainable development?

Let's start with solid waste disposal. In the United States we collect almost one ton of solid waste per person annually. Around a fourth of the material in solid waste facilities is construction debris, much of that from the demolition of older and historic buildings.

We all diligently recycle our Coke cans. It's a pain in the neck, but we do it because it's good for the environment. A typical building in an American downtown is perhaps 25 feet wide and 120 feet deep. If we tear down that one small building, we have now wiped out the entire environmental benefit from the last 1,344,000 aluminum cans that were recycled. We've not only wasted a historic building, we've wasted months of diligent recycling.

Driven in part by concerns for sustainable development, there is an emerging movement made up of planners, architects, landscape architects, and some developers. The movement wants us to stop building endless sprawl and start building better cities. Everybody has their own name for it—New Urbanism, Traditional Neighborhood Development, Transportation-Oriented Development—slightly different names but largely the same goals and principles. At the National Governors Association, they call it New Community Design. In the association's publication—*New Community Design to the Rescue*—they establish a set of principles, and they are these:

- Mixed use
- Community interaction
- Transportation/ walkability
- Tree-lined streets
- Open space
- Efficient use of infrastructure
- Houses close to the street
- Diverse housing
- High density
- Reduced land consumption
- Links to adjacent communities
- Enhances surrounding communities
- Pedestrian friendly

It's a great list. Building cities in that fashion would certainly advance the sustainable development agenda. But you know what? We don't need new community design to rescue us. That list of principles is exactly what our historic neighborhoods are providing right now. We just need to make sure they are protected. And by the way, the number of times the phrase "historic preservation" appears in their publication? Exactly zero.

If we want to slow the spread of strip-center sprawl, we must have effective programs of downtown revitalization. Throughout America we have seen downtowns reclaim their historic role as the multifunctional, vibrant heart of the city. Downtown is where I do most of my work. I visit 100 downtowns a year of every size, in every part of the country. But I cannot identify a single example of a sustained success in downtown revitalization where historic preservation wasn't a key component of that strategy. Not one. Conversely, the examples of very expensive failures in downtown revitalization have nearly all had the destruction of historic buildings as a major element. The relative importance of preservation as part of the downtown revitalization effort will vary, depending on the local resources, the age of the city, the strength of the local preservation groups, and the enlightenment of the leadership. But successful revitalization and no historic preservation? It ain't happening.

Next is the concept of embodied energy. I hadn't paid much attention to embodied energy, not until oil hit $70 a barrel. So I did a bit of research. *Embodied energy* is the total expenditure of energy involved in the creation of the building and its constituent materials. When we throw away a historic building, we simultaneously throw away the embodied energy incorporated into that building. How significant is embodied energy? In Australia they've calculated that the embodied energy in their existing building stock is equivalent to 10 years of the total energy consumption of the entire country.

Razing historic buildings results in a triple hit on scarce resources. First, we are throwing away thousands of dollars of embodied energy. Second, we are replacing it with materials vastly more consumptive of energy. What are most historic houses built from? Brick, plaster, concrete, and timber—among the least energy consumptive of materials. What are major components of new buildings? Plastic, steel, vinyl, and aluminum—among the most energy consumptive of materials. Third, recurring embodied energy savings increase dramatically as a building's life stretches over 50 years. You're a fool or a fraud if you claim to be an environmentalist and yet you throw away historic buildings and their components.

The World Bank specifically relates the concept of embodied energy with historic buildings saying, "the key economic reason for the cultural patrimony case is that a vast body of valuable assets, for which sunk costs have already been paid by prior generations, is available. It is a waste to overlook such assets."

I said earlier that in the U.S. we haven't generally made the connection between sustainable development and historic preservation, but that there was one notable exception. The exception is Smart Growth. Richard Moe brought the preservation movement—with many of us kicking and screaming—into the forefront of Smart Growth…as well we should be. There is no movement in America today that enjoys more widespread support across political, ideological, and geographical boundaries than does Smart Growth. Democrats support it for environmental reasons, Republicans for fiscal reasons, big city mayors and rural county commissioners support it—there are Smart Growth supporters everywhere.

The Smart Growth movement also has a clear statement of principles and here it is:

- Create a range of housing opportunities and choices
- Create walkable neighborhoods
- Encourage community and stakeholder collaboration
- Foster distinctive, attractive places with a sense of place
- Make development decisions predictable, fair, and cost effective
- Mix land uses
- Preserve open space, farmland, natural beauty, and critical environmental areas
- Provide a variety of transportation choices
- Strengthen and direct development toward existing communities
- Take advantage of compact built design.

> *If a community did nothing but protect its historic neighborhoods it will have advanced every Smart Growth principle. Historic preservation* is *Smart Growth.*

But you know what? If a community did nothing but protect its historic neighborhoods it will have advanced every Smart Growth principle. Historic preservation *is* Smart Growth. A Smart Growth approach that does not include historic preservation high on the agenda is stupid growth, period.

Economic Responsibility

Historic preservation is vital to sustainable development, but not just on the level of environmental responsibility. The second component of the sustainable development equation is economic responsibility. So let me give you some examples in this area.

An underappreciated contribution of historic buildings is their role as natural incubators of small businesses. It isn't the Fortune 500 companies that are creating the jobs in America. Some 85 percent of all net new jobs are created by firms employing fewer than 20 people. One of the few costs firms of that size can control is occupancy costs—rents. In downtowns and in neighborhood commercial districts a major contribution to the local economy is the relative affordability of older buildings. It is no accident that the creative, imaginative start-up firm isn't located in the corporate office "campus," the industrial park, or the shopping center—it simply cannot afford those rents. Historic commercial buildings play the natural business incubator role, usually with no subsidy or assistance of any kind.

Pioneer Square in Seattle is one of the great historic commercial neighborhoods in America. The business management association there did a survey asking why Pioneer Square businesses chose that neighborhood. The most common answer? That it was a historic district. The second most common answer? The cost of occupancy. Neither of those responses is accidental.

I'm often introduced as a preservationist, but I'm really an economic development consultant. The top priorities for economic development efforts are creating jobs and increasing local household income. The rehabilitation of older and historic buildings is particularly potent in this regard. As a rule of thumb, new construction will be half materials and half labor. Rehabilitation, on the other hand, will be 60 to 70 percent labor with the balance being materials. This labor intensity affects a local economy on two levels. First, we buy a HVAC system from Ohio and lumber from Idaho, but we buy the services of the plumber, the electrician, and the carpenter from across the street. Further, once we hang the drywall, the drywall doesn't spend any more money. But the plumber gets a haircut on the way home, buys groceries, and joins the YMCA—each recirculating that paycheck within the community.

Many people think about economic development in terms of manufacturing, so let's look at that. In Oregon for every million dollars of production by the average manufacturing firm, 24.5 jobs are created. But that same million dollars in the rehabilitation of a historic building? Some 36.1 jobs. A million dollars of manufacturing output in Oregon will add, on average, about $536,000 to local household incomes. But a million dollars of rehabilitation? About $783,000.

Seattle's historic Pioneer Square neighborhood has become well known for providing affordable spaces with character for new software companies and other start-up businesses. Photo by Tim Thompson, courtesy of the Seattle Convention and Visitors Bureau.

Of course the argument can be made, "Yeah, but once you've built the building the job creation is done." Yes, but there are two responses to that. First, real estate is a capital asset—like a drill press or a boxcar. It has an economic impact during construction, but a subsequent economic impact when it is in productive use. Additionally, however, since most building components have a life of between 25 and 40 years, a community could rehabilitate 2 to 3 percent of its building stock per year and have perpetual employment in the building trades. And these jobs can't be shipped overseas.

Some economists and politicians argue that in economic downturns public expenditures should be made to create employment. As you all know, politicians' favorite form of public works is building highways.

David Listokin at the Center for Urban Policy Research calculated the relative impact of public works. Let's say a level of government spends $1 million building a highway. What does that mean? It means 34 jobs, $1.2 million in ultimate household income, $100,000 in state taxes, and $85,000 in local taxes. Or we could build a new building for $1 million, which translates to 36 jobs, $1.2 million in household income, $103,000 in state taxes, and $86,000 in local taxes. Or we could spend that million rehabilitating a historic building, which means 38 jobs, $1.3 million in household income, $110,000 in state taxes, and $92,000 in local taxes. You tell me which public works project has the most economic impact.

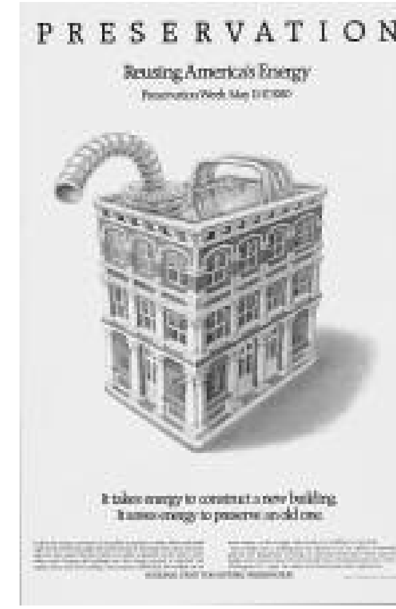
Another area of preservation's economic impact is heritage tourism. In a Virginia study a few years ago, we analyzed the patterns of heritage visitors. We defined heritage visitors as those who did one or more of the following: visited a museum (in Virginia around 90 percent of the museums are history museums), visited a Civil War battlefield, or visited a historic site. We contrasted those patterns with visitors to Virginia who did none of those things. Here's what we found: Heritage visitors stay longer, visit twice as many places, and on a per trip basis spend two and one-half times as much money as other visitors. Wherever heritage tourism has been evaluated, this basic tendency is observed: Heritage visitors stay longer, spend more per day, and, therefore, have a significantly greater per trip economic impact.

The University of Florida and Rutgers University did an economic analysis of historic preservation in Florida. Florida is not a state that immediately comes to mind as being heritage tourism based. We think of Disney World, beaches, and golf courses. Tourism is the largest industry in Florida. But just the heritage tourism portion of that industry has impressive impacts, bringing in more than $3 billion in visitor expenditures and half a billion in taxes, and providing over 100,000 jobs. While most of the jobs, predictably, are in the retail and service industries, in fact nearly every segment of the economy is positively affected.

The area of preservation's economic impact that's been studied most frequently is the effect of local historic districts on property values. It has been looked at by a number of people and institutions using a variety of methodologies in historic districts all over the country. The most interesting result is the consistency of the findings. By far the most common conclusion is that properties within local historic districts appreciate at rates greater than the local market overall and faster than similar non-designated neighborhoods. Of the several dozen of these analyses, the worst-case scenario is that housing in historic districts appreciates at a rate equivalent to the local market as a whole.

Like it or not, we live in an economically globalized world. To be economically sustainable it's necessary to be economically competitive. But to be competitive in a globalized world a community must position itself to compete not just with other cities in the region but with other cities on the planet. A large measure of that competitiveness will be based on the quality of life the local community provides, and the built heritage is a major component of the quality of life equation. This lesson is being recognized worldwide. Here's what the Inter American Development Bank has to say: "As the international experience has demonstrated, the protection of cultural heritage is important, especially in the context of the globalization phenomena, as an instrument to promote sustainable development strongly based on local traditions and community resources."

What neither the supporters nor the critics of globalization understand is that there is not one globalization but two—economic globalization and cultural globalization. For those few who recognize the difference, there is an unchallenged assumption that the second is an unavoidable outgrowth of the first. Economic globalization has widespread positive impacts; cultural globalization ultimately diminishes us all. It is



This 1980 poster produced by the National Trust to promote Preservation Week shows that preservationists have long understood the relationship between historic preservation and energy conservation.

Ecotrust's conversion of a Portland, Ore., warehouse into the Jean Vollum National Capital Center was the first historic restoration project in the nation to receive LEED Gold certification—showing how reuse of a historic building and energy-efficient construction practices can go hand in hand. The center houses Ecotrust headquarters and a mix of environmentally conscious nonprofits and businesses.

through the adaptive reuse of heritage buildings that a community can actively participate in the positive benefits of economic globalization while simultaneously mitigating the negative impacts of cultural globalization.

So there are some ways that historic preservation contributes to sustainable development through environmental responsibility and through economic responsibility. But I saved the third area—cultural and social responsibility—for last, because in the long run it may well be the most important.

Cultural and Social Responsibility

First, housing. In the United States today we are facing a crisis in housing. All kinds of solutions—most of them very expensive—are being proposed. But the most obvious one is barely on the radar screen: Quit tearing down older and historic housing. Homes built before 1950 disproportionately house people of modest means—in the vast majority of cases without any subsidy or public intervention of any kind. So you take these two facts—there is an affordable housing crisis and older housing is providing affordable housing—and one would think, "Well, then, there must be a high priority to saving that housing stock." Alas, not so.

For the last 30 years, every day, seven days a week, 52 weeks a year, we have lost 577 older and historic houses, more than 80 percent of them single-family residences. Most of these houses were consciously torn down, were thrown away as being valueless.

For our most historic houses—those built before 1920—in just the decade of the 1990s, 772,000 housing units were lost from our built national heritage.

Affordable housing is central to social responsibility; older and historic homes will continue to provide affordable housing if we just quit tearing them down.

At least as important as housing affordability is the issue of economic integration. America is a very diverse country—racially, ethnically, educationally, economically. But on the neighborhood level our neighborhoods are not diverse at all. The vast majority of neighborhoods are all white or all black, all rich or all poor. But virtually everywhere I've looked in America, the exception is in historic districts. There rich and poor, Asian and Hispanic, college educated and high school dropout, live in immediate proximity, are neighbors in the truest sense of the word. That is economic integration, and sustainable cities are going to need it.

Economic development takes many forms—industrial recruitment, job retraining, waterfront development, and others. But historic preservation and downtown revitalization are the only forms of economic development that are simultaneously community development. That too is part of our social responsibility.

Finally, I'd ask you to take a moment and think of something significant to you personally. You may think of your children, or your spouse, or your church, or your childhood home, or a personal accomplishment of some type. Now take away your memory. Which of those things are significant to you now? None of them. There can be no significance without memory. Those same things may still be significant to someone else, but without memory they are not significant to you. And if memory is necessary for significance, it is also necessary for both meaning and value. Without memory nothing has significance, nothing has meaning, nothing has value.

That, I think, is the lesson of that old Zen koan, "If a tree falls in a forest and no one hears, did it make a sound?" Well of course it made a sound; sound comes from the vibration of molecules and a falling tree vibrates molecules. But that sound might as well not have been made, because there is no memory of it.

We acquire memories from a sound or a picture, or from a conversation, or from words in a book, or from the stories our grandmother told us. But how is the memory of a city conveyed? Here's what Italo Calvino writes: "The city...does not tell its past, but contains it like the lines of a hand, written in the corners of the streets, the gratings of the windows, the banisters of the steps … every segment marked in turn with scratches, indentations, scrolls."

The city tells it own past, transfers its own memory, largely through the fabric of the built environment. Historic buildings are the physical manifestation of memory—it is memory that makes places significant.

The whole purpose of sustainable development is to keep that which is important, which is valuable, which is significant. The definition of

Historic preservation is a responsibility movement rather than rights movement. It is a movement that urges us toward the responsibility of stewardship, not merely the right of ownership.

sustainable development is "the ability to meet our own needs without prejudicing the ability of future generations to meet their own needs." We need to use our cities and our historic resources in such a way that they are available to meet the needs of future generations as well.

Historic preservation makes cities viable, makes cities livable, makes cities equitable.

I particularly appreciate that the broadened concept of sustainable development is made up of responsibilities—environmental responsibility, economic responsibility, and social responsibility.

Today throughout America there are thousands of advocacy movements. Most of them are "rights" movements: animal rights, abortion rights, right to life, right to die, states rights, gun rights, gay rights, property rights, women's rights, and on and on and on. And I'm for all of those things—rights are good. But any claim for rights that is not balanced with responsibilities removes the civility from civilization, and gives us an entitlement mentality as a nation of mere consumers of public services rather than a nation of citizens. A consumer has rights; a citizen has responsibilities that accompany those rights. Historic preservation is a responsibility movement rather than a rights movement. It is a movement that urges us toward the responsibility of stewardship, not merely the right of ownership. Stewardship of our historic built environment, certainly, but stewardship of the meanings and memories manifested in those buildings as well.

Sustainability means stewardship. Historic preservation is sustainable development. Development without historic preservation is not sustainable. That's what your stewardship is assuring today, and future generations will thank you for it tomorrow.

Donovan D. Rypkema is a principal in PlaceEconomics, a Washington, DC–based real estate consulting firm.

"The past is alive in us": The Imperative for Cultural Stewardship

Roberta Conner

I am delighted to be here today as an ambassador for my tribe and for other tribes as well. We are the very physical manifestations of the dreams and prayers of our ancestors. Those of us who come from cultures who have survived much genocide and termination and holocaust understand what those prayers were. We repeat them ourselves.

I am here today because I want to celebrate the survival of our people. I am here because I care about the future of our people and your people and the places where we live.

It is hard sometimes to tell people about why it's important to remember. We have been accused of living in the past, of being desirous of times that cannot be revisited. Tribes have been called primitive for a long time. But we do not live in the past; the past is alive in us. It is alive in us as we carry the ancient knowledge of our homelands forward. But without our languages that ancient knowledge is lost. Languages are a window to the world that you do not know, that I do not know, that my grandfather always spoke of and I imagined. Today, we want others to understand that our traditional ways are not holy customs or curious traditions. They are the lifeblood of a people.

We want people to understand these things so that they can help us protect them. But protecting culture for us is a goal that has no walls and does not require buildings. It is our job to teach our children and children yet unborn about the past. Why? Why is that so important to us?

Identities arose from your village and your family. Your relations, your kin were derived from your language, your diet, and where you traveled and lived. There were not a lot of categories of people. You were either relatives, friends or allies, enemies, or strangers. The divisions of people were not by color or by class, but by how we lived. Knowing who we were in

The Tamastslikt Cultural Institute in Pendleton, Ore., opened in summer 1998, presents and preserve the history and culture of the Cayuse, Umatilla, and Walla Walla tribes. Visitors can watch demonstrations of ancient lifeway skills by local tribal peoples at the museum's living culture museum. Photo courtesy of Tamastslikt Cultural Institute.

ancient times is critical in answering today's problems, because that knowledge tells us how the world is supposed to work when the world is right, when the world is in balance.

As a director of a regional tourism anchor, I have been asked to talk about balancing economic development with preservation. Let me tell you one of the cardinal rules: Decide what you don't sell first. Decide what you don't tell first. Write it down so you remember the agreement about what is not for sale and keep it private. Use it in staff-only meetings, but don't tell anyone else, including the press. Choose that which is sacred and that which you must hold close to your heart and protect it from exploitation—because our people know for the last 200 years what that exploitation costs. It's a grave expense.

When you want to balance preservation with economic development, remember that we are human beings first, not Indians, not travelers, not visitors, not attendance counts. Humanize the discussion. If you humanize the discussion then we can begin to talk about who we truly are.

We are people who emanate from the land. We do not come from somewhere else. Tribes come from the land and do not intend to ever be from anywhere else. We have been where we are for thousands and thousands of years, and intend to keep that tradition of being in our homes in our homelands—not in the wilderness of Thomas Jefferson's imagination.

We have no word for wilderness, nor a word for art. In order to live, we had to take the lives of other things: grass, tree roots, animal hides. The responsibility that goes along with the right to take that life is to make it beautiful. It is an ethic to some, a principle to others, but it is balance. You have taken a life. Do not waste it or throw it away. Make it beautiful out of respect. It is the manner in which you do things that matters.

Repatriating Our Knowledge and Culture

Anthropologists, when my uncles and mother were in college and in the armed forces, predicted our cultural extinction. It has not occurred. We do not intend to allow that to happen. How do we tactically prevent it? Since genocide and termination have not succeeded and assimilation is still an ongoing experiment, what are we doing at the Confederated Tribes of Umatilla and at Tamástslikt? We are repatriating knowledge.

We have held convocations of scholars, tribal elders, and tribal students to bring the scholars who have studied with our previous generations back to our community to meet with elders—the children or grandchildren of the people they met. They took down our language and recorded place names and fishing sites and data. Many of these scholars are quite elderly and some have recently passed away. We re-created these relationships between students of our tribes and scholars who have studied our tribes and elders of our tribes. We value the ancient knowledge and it has to come back to us.

Most people think of tradition and culture for tribes as songs, ceremonies, dances. For us it is much more than that. It is the very cradle of our existence. It is the land and the foods that grow naturally from that land, the animals that sustain themselves off of that natural landscape.

For us to preserve our culture, our tribes had to restore a species to a river, but before we could do that we had to restore water to the river. Preserving a culture does not stop with buildings. It does not start in language class. It is the entire landscape. Our tribes had to work to put spring and fall Chinook salmon back in the Umatilla and Walla Walla Rivers. We have reintroduced lamprey and are helping to sustain river mussels. Our culture requires that we have these foods.

When we restore the water and these species other

Preserving a culture does not stop with buildings. It does not start in language class. It is the entire landscape.

things happen, just like in economic development—osprey come back, cougars abound, bears go fishing. There are other results from restoring part of the ecosystem, but what they do for us is give us back our culture. The core of our culture is salmon, as buffalo is for other tribes. We could not live without roots or without berries, including those that have the highest antioxidant properties on this continent. We have to have them so we have to restore them. They are part of our cultural landscape without which we cease to be tribal people. To preserve our culture and to balance preservation in modern times, we are protecting and perpetuating a land that is different than the one the grandparents spoke of, but that is nonetheless unique.

Our languages are being taught and are being documented. They will be published as we present to the public a native place–name atlas to perpetuate the use of these names. These native place names are only abbreviations for a story about how that landscape was formed, because our stories go back to the forming of the mountains, the melting of the glaciers, the coming out of the cold times, the living in the cave times, the times when the mountains were hurling rocks and fire at each other, volcanoes. We are publishing our knowledge because we have to have a consistent form of instituting this information in our tribal school system as well as for public school students and boarding school students who do not live at home with their grandparents or parents.

We will publish the first book of our history from our perspective next year. We will publish a counting book in four languages, one of which is extinct. We are—as tribes all across this continent (with or without casinos) are—trying to rebuild nations, trying to restore landscapes, trying to protect species, and trying to teach our children why all of that is important.

In order to keep our children there where they can learn the language, practice their traditions, help us gather and protect the sacred foods, we must provide jobs for them, and those have to be meaningful jobs. One of the jobs at our Institute in visitor services interpretation has at the helm a young man who cannot get enrolled in our tribe, one of the arbitrary externally imposed systems that hinder us today. He is a carrier of ancient worship songs, a championship dancer, and a teacher of one of the four languages. Indubitably he is a member of our tribe whether or not he is enrolled. The knowledge that we carry that sustains us matters most.

Responsibilities and Opportunities Going Forward

How do we go forward from here? How can we face the future when we have fairly insurmountable odds? With certainty and confidence—sometimes with pain and anger—because our people have been from these places forever and we will be from here forever. We can endure racism and tolerate poverty and survive because it is our home, and now, we share it with you. With the right to our land comes the responsibility of stewardship for the cultural landscape and the species that belong here, that the creator put here and that sustain us all.

My greatest hope for tribes is that we are able to restore our tribal pedagogy. What might that look like? What would that be? It would be more than a cliché that it takes a village to raise a child. We would banish people who put us at risk, drug dealers and batterers; and we would rid ourselves of soda pop, given our propensity for diabetes and high blood pressure. There would be no orphans. Children and elders would never know hunger, especially for traditional foods that are very healthy for us. All of our people would understand how to pray and cleanse themselves before they take the lives of the animals that sustain us. We would reinvigorate the spiritual and physical athleticism of our people. Our people's personal power has been unsurpassed historically. We could endure much that was very, very difficult because we were raised to do that. We were physically athletic, not in the condition we

At the Tamastslikt living culture museum, a longhouse and other types of early dwellings can be viewed outside the museum exhibit area. Photo courtesy of Tamastslikt Cultural Institute.

Wherever you are, you are in someone's tribal home land, every one of you. You have the opportunity to encourage and orchestrate and promote the welcoming back of tribal people to their landscapes, however changed they are.

are now, and the standards of our people would once again be restored.

You can help us by delivering clear messages of stewardship wherever you are. You can help us with site protection by teaching people to respect land as well as buildings. You can insure that our cultural sites and information about cultural sites is protected as much as possible. You can adhere to the Indian Arts and Crafts Act in selling merchandise. You can help protect places where there are no buildings and where there should never be any buildings. I want you to understand that our tribal lands, sacred places, are holy lands, and acts of desecration and vandalism are terrorist acts against us. They are against our people.

You have enormous opportunities. Wherever you are, you are in someone's tribal home land, every one of you. You have the opportunity to encourage and orchestrate and promote the welcoming back of tribal people to their landscapes, however changed they are. I can guarantee you from our work in the Wallowas, in the Walla Walla and Umatilla basins, and all over this country, the land is happy to hear our songs and welcomes our prayers for it.

This year is the 150th anniversary of our treaty. The Umatilla, Cayuse, and Walla Walla ceded more than six million acres in 1855 to the United States government. We reserved to ourselves a half-million acres that has been diminished by many acts to 172,000 acres now. In that treaty are solemn obligations, solemn promises from the United States government to us; the balance of rights and responsibilities. Without our treaties you do not hold legal claim to our land. It would behoove you and all citizens of this country to honor those treaties today.

Roberta Conner is the director of the Tamástslikt Cultural Institute, the interpretive center and museum owned and operated by the Confederated Tribes of the Umatilla Indian Reservation of which she is also a member.

Celebrating Preservation's Story: "It's your memory. It's our history. It's worth saving."

Anthony C. Wood

I hope the irony of my being here is obvious to us all. Before me is a room full of serious preservationists, many of you professionals, most of you having traveled countless miles at great expense. On top of that, you plunked down an extra $35 dollars to hear the earth-shattering and cutting-edge message that preserving history is important.

What's wrong with this picture?

I think it is safe to assume that most of you regularly climb up on your soapbox to passionately preach to your neighbors, your elected officials, property owners, and the press that preserving history is the right thing to do. Now I'm here on my soapbox proclaiming that your history—the work you do, the work your predecessors have done, the accomplishments of your organizations—is a valuable and extremely fragile legacy. It is a rich resource to be managed and mined, a crop of intellectual capital to be harvested, a treasure trove of knowledge and inspiration—you get the point: It's valuable and needs to be protected.

Well, brothers and sisters in preservation, I'm here today to preach that indeed the history of preservation, like the history of our country, like the history of the place you call home, like the history of dead boring white men, or dynamic dead women, or like the history of immigration, slavery, organized labor, or roadside architecture—our history is important. After all it's your memory, it's our history, and it's worth saving.

Is there a need for me to preach this gospel today? Sadly, yes. How many of your hometowns have a written history of their preservation movement? New York City is celebrating the 40th anniversary of the passage of our landmarks law and we still lack a history of how the law came into being. How many of your organizations have a written history of their accomplishments? Routinely I work with young preservation colleagues who have no sense of preservation's recent past, let alone its distant past, let alone the history of the organization for which they work. It is not their fault; how would they know it? Through osmosis?

So why have we as preservationists devoted so little energy and shown seemingly such little interest in our own history? Is this a case of the shoemaker's children going barefoot? I like to think that we have been so busy saving other people's history that we haven't had time for our own. I do not want to think it is because we don't believe our own history is important. Actually, I think the real explanation mirrors one theory on the evolution of civilizations. As a community, for decades and decades, preservation has needed all hands on deck to confront the issue of basic survival: keeping the wrecking ball at bay, keeping the roof patched, building a constituency for preservation, passing legislation—so there has not been the capacity to devote significant energy to gathering and preserving our history. The good news is times have changed—and not a moment too soon.

Why Document Our History?

Why is it so important to document our own history? First, it has practical application. For example it provides you that insider knowledge needed to appreciate preservation in-jokes like the title of this talk. How many of you recognize the phrase: "It's your memory. It's our history. It's worth saving?" If you knew history you'd recognize it as the National Trust's tag lines from more than a decade ago.

Why is preservation's history important?

Lost in the rubble of many a cherished demolished building are lessons that could save the next threatened gem. Behind the passage of a local landmarks ordinance is frequently found the tale of a threatened or lost local icon. Scratch the surface of a preservation victory and one is likely to find an "average citizen" whose David vs. Goliath struggle verges on the miraculous.

Again, if you knew preservation's recent history you'd recognize these last few sentences as having been lifted verbatim from an article that appeared in *Historic Preservation News* in 1994 entitled "Preservation Starts at Home: Preserving Our Own Story." OK, so no one listened to me then but this time I've got a captive audience. No one leaves until they take the pledge that they will go home and start documenting, preserving, and celebrating their own chapter of preservation's history.

Those of you who know me are aware that first and foremost I am a preservation advocate. So why am I beating this drum, and why did I and a small band of like-minded preservationists launch a group, the New York Preservation Archive Project, dedicated to documenting, preserving, and celebrating the history of preservation in New York? I consider documenting, preserving, and celebrating preservation's story one of the greatest advocacy acts imaginable.

How so? For a general audience, it is important that the story of how historic sites were saved is told. Without knowing this, citizens just assume historic places are saved as a matter of course—we know better. But how are they to know that preservation requires constant vigilance, and their involvement, if the story of a site's preservation is not part of its interpretation?

For preservationists, knowing our own history is empowering in countless ways. There is the sense of power that comes from belonging to a grand tradition. We have heroes and heroines of our own to inspire and guide us. I frequently take comfort in lessons learned from the life of Albert Bard, the forgotten civic leader whose name is on the authorizing legislation providing the legal foundation for New York's landmarks law. For more than 40 years he fought to advance the notion that aesthetic regulation was a proper use of the police power. Finally at the age of 89 he saw it come to pass. Lesson learned: If one lives long enough and is persistent enough, one can prevail.

The thoughtful preservationists Randy Mason and Max Page ask in their book, *Giving Preservation a History*, "How might preservation look different in the future if practitioners examined critically their movement's history." How can we begin to "examine critically" our work if we

For the 40th anniversary of the start of the demolition of New York's Pennsylvania Station, the New York Preservation Archives Project tracked down and brought together veterans of the fight to save it. The videotaped the event, plus additional memories gathered at "oral history stations," could inform and inspire those engaged in today's preservation battles. Photo by Steven Tucker, Courtesy of the New York Preservation Archive Project.

Lacking a sense of time, self-reflection, and context, preservationists can either find themselves reinventing the wheel or desperately clinging to the wheel when it should be abandoned for jet propulsion.

haven't even documented it?

Preservation's history provides a needed sense of perspective and context for our work. Perhaps this is the most important reason to capture it. Do you want to go to a doctor practicing medicine the same way doctors did 40 years ago? Preservation often seems oblivious to the fact that it too is subject to the passage of time; it too happens within a historic context. Lacking a sense of time, self-reflection, and context, preservationists can either find themselves reinventing the wheel or desperately clinging to the wheel when it should be abandoned for jet propulsion.

Developing an Archival Mindset

In speaking today, I have a modest goal—to transform the entire culture of the historic preservation movement. I want us to be a movement that consciously documents, preserves, and celebrates its own history. However, I am willing to redefine success as having won over a handful of converts.

As preservationists we need to develop an archival mindset as we go about our work. Now I understand you and your organizations have lots of free time and oodles of extra money to take on a new assignment. Hence, you will be disappointed to learn you don't need them for this task. They are nice but not essential. In New York we've managed to move this agenda forward without lots of either.

In part we do this by following three operating mantras. The first is: "One is the loneliest number." We always try to work in partnership with other organizations. We are fully aware that our mission and cause are not at the top of anyone's priority list but our own; we realize to reach a broader audience we have to "imbed" ourselves in other organizations.

When we did our program on the long-forgotten civic leader Robert Weinberg—an architect, a passionate defender of Greenwich Village, and a member of multiple civic organizations—we first reminded the organizations in which he had been involved of his existence and then partnered with them to bring our program to their audience. In true Tom Sawyer paint-the-fence fashion, we were able to leverage their membership lists, mailings, websites, you name it, to get our message before new and broader audiences.

Our second operational mantra is captured in the old farm adage, "No part of the pig is wasted except the squeal." And when we are audiotaping we don't even waste that. The point is we get double or triple duty out of almost every project we undertake. Take our oral history work. Those transcripts become content for our website; we videotape the interview and it becomes part of our cable television series. We invite an audience to watch and, *voilà*, we have a public program.

Our final operating mantra is to "walk the talk." We have to live the archival mindset, which means document, document, document. Obvious as this is, if you don't think about documenting your work, it does not happen. We try to capture all that we do on video or audiotape. Since many of our events not only present information but gather it from the speakers and from guests in the audience, if we don't document it, we lose it.

Five Easy Steps

I know at this moment you are asking yourself, "How can I help Tony change the culture of preservation? What are the five easy, low-cost/no-cost things I can do when I get back home?" Well, here's the list:

1. Make sure that preservation's story is included in all the stories you are already telling. Do your historic house tours and your walking tours of historic districts tell the story of how these places got saved? They should. Yes, it is important to know the architect of the building but what of the preservationists whose efforts spared it from demolition? If there hadn't been citizens fighting to save those buildings, the public would be seeing them in a book, not on your walking tour.

2. Use naming opportunities to keep the legacies of preservation heroes and heroines alive. Name your existing awards, your donor categories, your events after early leaders or great events in the history of preservation in your community. Our annual fundraising event is the Bard Birthday Benefit Breakfast Bash. We keep Bard's memory alive while filling our coffers.

3. Use your anniversaries. At the archive project, we consider ourselves the Hallmark Cards of preservation; we are the anniversary people. Celebrate your anniversaries and make those celebrations substantial and meaningful.

On October 28, 2003, we commemorated the 40th anniversary of the start of the demolition of Pennsylvania Station. As part of this we wanted to salute the courageous individuals who took some concrete action to try and save the station. We researched old newspaper stories, old hearing records, and unearthed other archival material. We developed a database of almost 300 people who had written letters, testified, or picketed in defense of Penn Station. We went to work to track them down. We learned that about a third had already "gone to their reward." We did make contact with dozens of surviving veterans spread across the country and even some in Europe. They were moved that someone remembered.

The program featured a series of readings about Penn Station, ranging from the lyrical passage in Thomas Wolfe's *You Can't Go Home Again* to the now-famous *New York Times* editorial:

Until the first blow fell no one was convinced that Penn Station really would be demolished or that New York would permit this monumental act of vandalism…

It concludes:

Any city gets what it admires, will pay for, and ultimately, deserves. Even when we had Penn Station, we couldn't afford *to keep it clean. We want and deserve tin-can architecture in a tin-horn culture. And we will probably be judged not by the monuments we build but by those we have destroyed.*

Yes, preservation has its own literary classics. Isn't it time we rediscover them?

Reading at the event were preservation luminaries such as the authors Tony Hiss and Roberta Gratz; participants from the original picketing of Penn Station, Peter Samton and Richard Kaplan; and preservation leaders Tony Tung and Adele Chatfield Taylor. Projected images of the station and its demolition accompanied the readings. The sense of outrage over this loss, even 40 years later, was still palpable in the room. Many eyes in the audience filled with tears. Of course, we videotaped it.

During the reception we honored all the veterans who had made it to the event. Inspired by the National Trust's advisor emeritus black ribbons, we had "Penn Station 40th" black ribbons printed up. We had two oral history stations gathering memories from the veterans and others who had a Penn Station story to tell. Some of the veterans had not seen each other for 40 years. The event honored the past but in the process inspired and energized those fighting preservation's battles today.

4. Go out and capture those memories. Remember, it's all about the people. Get those who lived the story to tell it; capture it through their eyes. We do straightforward oral histories in office settings and we've also spiced it up, creating other formats allowing for more public engagement and involvement. Recently we did a series of programs called "Sages and Stages." In an intimate setting, we organized cross-generational conversations on long-standing preservation issues. We paired an established preservation leader (the Sage) with a young emerging preservation leader. A series of lead questions were prepared in advance and the young leader used them to generate a conversation with the Sage. The audience was then invited to join in.

One in our series focused on historic districts. The Sage was Otis Pratt Pearsall who was involved in the campaign to protect New York City's first historic district, Brooklyn Heights, back before there even was a landmarks law. He was interviewed by Andrew Berman, the executive director of the Greenwich Village Society for Historic Preservation, the organization largely responsible for achieving the designation of the city's then newest historic district, the Gansevoort Market Historic District. The subject and the participants brought more than 40 years of preservation history spanning over 80 historic districts to the table. Of course, the program was videoed and became part of our television series.

We have developed another format that combines a traditional slide lecture with an oral history "open mike." The lecture is based on original research conducted on an important yet forgotten preservationist. In the course of the research we identify individuals who knew the historic figure (and are still living) and arrange for them to come to the program. After the slide lecture they come to the mike and add their memories. We then open the mike to anyone in the audience with other memories to add. Of course, the session is taped and transcribed. And, yes, it becomes a cable television show.

5. My last suggestion is for you to be good stewards of your own history and your own records. By you I mean both you as individual preservationists and you as members of preservation organizations. As you go about doing your work, remember at some point in the future someone could be interested in it. Don't make them piece it together from press clippings and odd scraps of paper—I've tried, it isn't pretty. Write up case studies of your efforts. Even if all you have time to do is write a memo to the file, do it. In New York today we are witnessing perhaps the most sophisticated grassroots preservation battle the city has ever seen: the battle to save 2 Columbus Circle. Win, lose, or draw—in the future preservationists are going to want to study this effort. What will they have to study if it isn't documented along the way?

So keep and treat your files as though they are what they are, historic records. Develop an organizational archive. If you have personal papers documenting an important episode in preservation's history, don't expect your heirs to know they are important; make arrangements for their future. Too many important papers have gone to the dumpster instead of the archive.

"Just do it"

In closing, I urge you to embrace one final mantra, *As you go about doing your work, remember at some point in the future someone could be interested in it.*

Nike's "Just do it." Don't get overwhelmed by the thought of all that it will involve. Remember, as preservation's history shows time and again, it is those who did not know that they could not save the endangered site who, indeed, do save it.

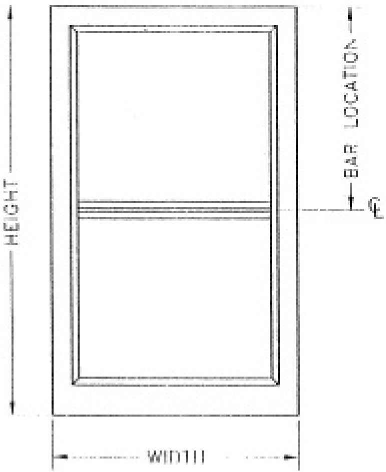
My interest in preservation's history began innocently enough. Some years ago, when I moved to New York as an aspiring preservationist, I wanted to read the history of the movement I hoped to join. Discovering there was nothing to read, I set out in search of preservation's story. Along the way I've conducted oral histories, explored archives, bent many ears, launched an organization, raised some money, and have been accused of starting a cult worshiping that great unappreciated preservationist Albert Bard.

Currently I am at work on a book you all will be buying for Christmas 2007 called *Preserving New York: Winning the Right to Protect the City's Landmarks*. It tells the story of the people and places, the buildings and the battles, and the politics and processes that led to the passage of New York City's landmarks law—at least that's the rap for the Oprah show. With some luck it will be followed by a work on the great Bard—and I don't mean that English fellow.

As you might imagine, if some 25 years ago I had known what I was getting into, I'd never have taken the first step down this path. The good news is if I can do this, you can too.

I can promise you that preservation's history will never bore you and it never ceases to inspire. Documenting, preserving, and celebrating your community's preservation history will better equip your community to successfully meet the challenges ahead. As a movement we need the perspective and context that only come from knowing our own past. Unfortunately, in this case, time is not on our side. So, remember, "It's your memory. It's our history. It's worth saving." Now go home and do something about it.

Anthony C. Wood is the founder and chairman of the New York Preservation Archive Project.



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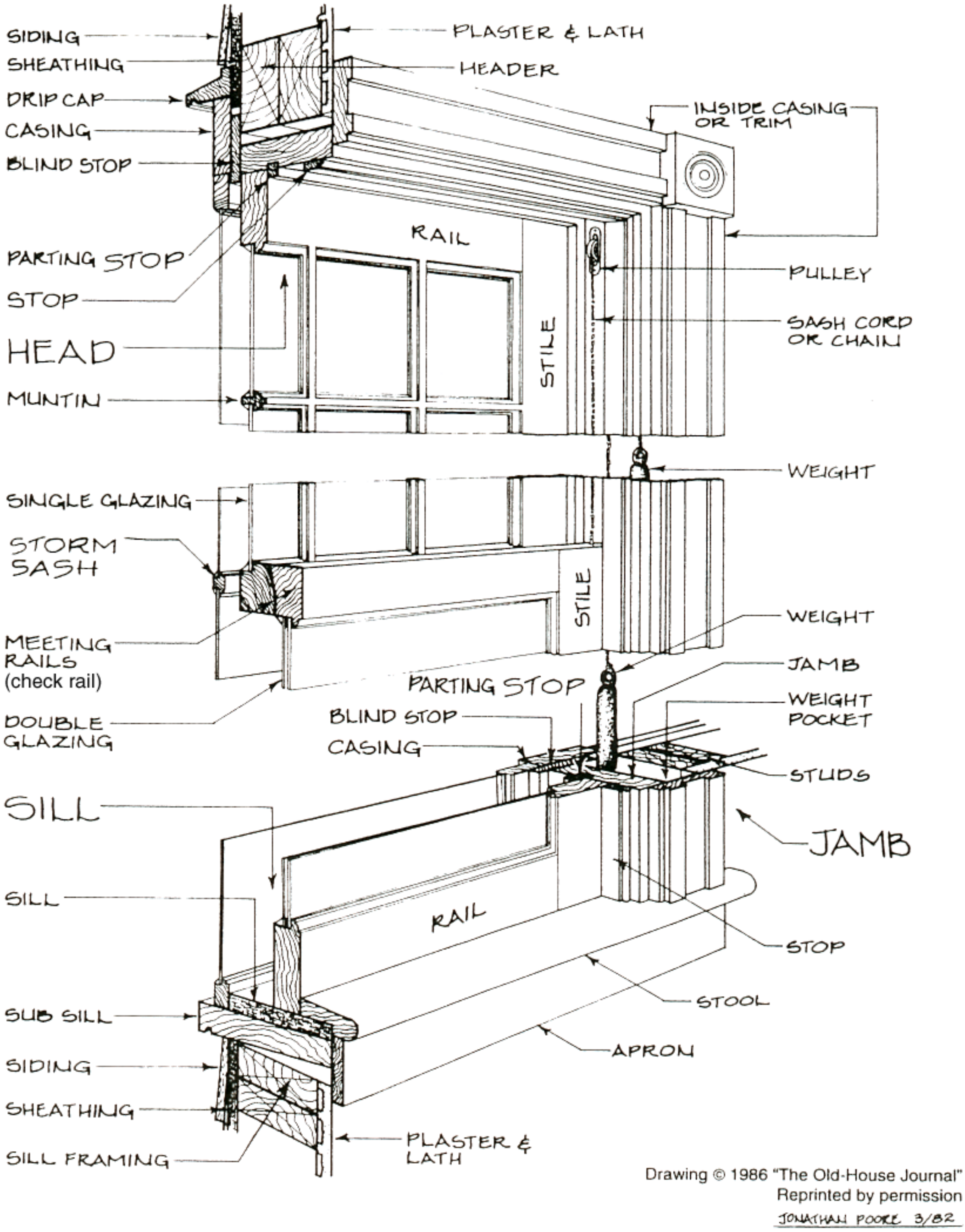

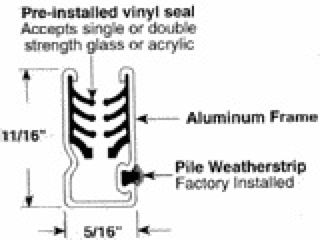

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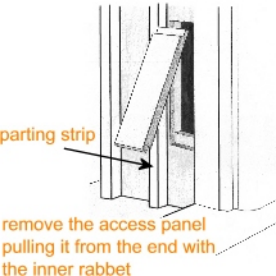
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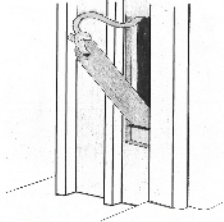

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