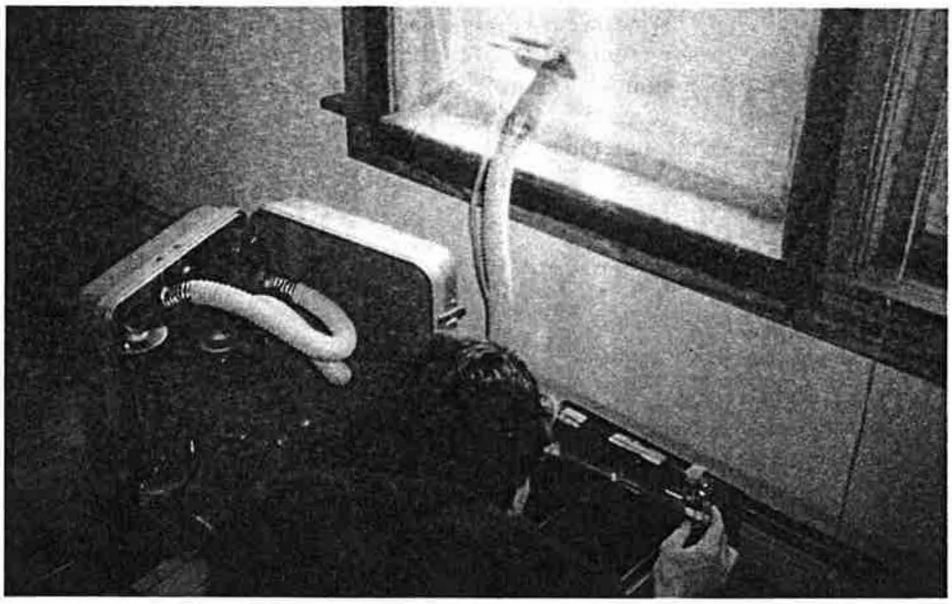
Windows are where we often look to improve the energy performance in old homes. But don't rip out those old sashes yet. A field study in Vermont suggests that "remove and replace" is not necessarily the way to go when it comes to old windows.

Creating Windows of Energy-Saving Opportunity

by Andrew M. Shapiro and Brad James



ANDREW SHAPIRO

Brad James sets up a test rig to measure air leakage around a window.

Renovating historic homes is a tricky and sometimes onerous task. The desire to retain the historic character of the building, and in some cases the actual historic material, competes with the desire to improve energy performance. One particularly difficult question that renovators of historic buildings often confront is what to do about windows.

From their handmade glazings to their crafted muntins, old windows add much to the character and charm of historic homes. But just looking at their loose jambs and leaky sashes can make an energy auditor shudder. Although the tendency among some contractors has been to replace the windows in older homes, until recently, there has been very little data available to guide renovators in choosing the most energy-efficient window rehab option (See "Energy-Efficient Window Retrofits," *HE* Jan/Feb '97, p. 35).

To help fill this data gap and supply additional guidance to renovators, we evaluated the thermal efficiency of more than 150 windows in 29 old New England homes and one municipal building. We determined the energy savings and costs associated with different renovation strategies, from simply weatherstripping to replacing the entire sash. The study was funded by the National Center for Preservation Technology and Training and the Vermont Division of Historic Preservation.

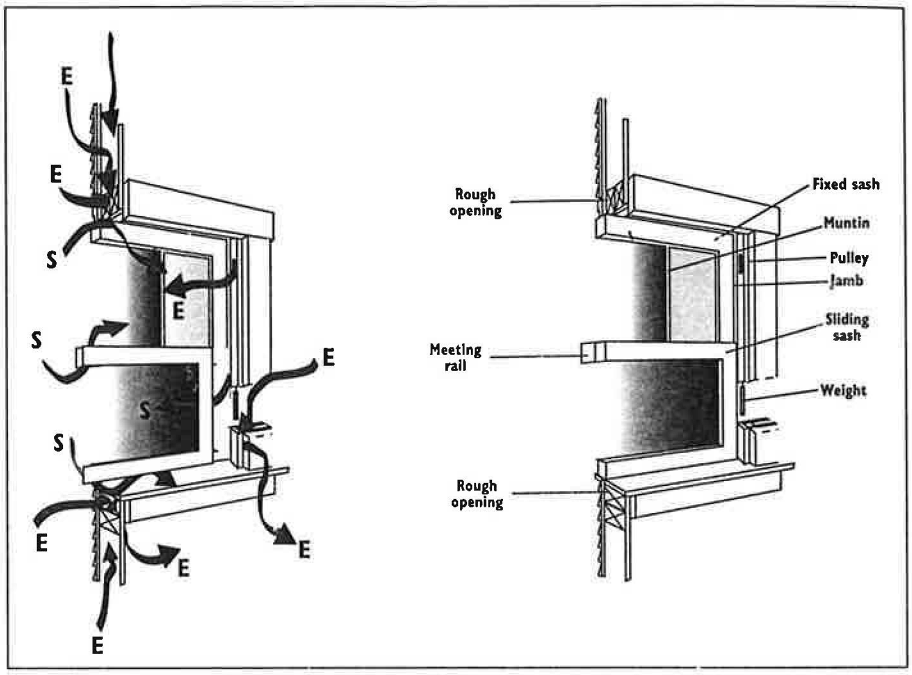


Figure 1. On the left, typical air leakage sites with Sash Leakage, S, and Extraneous Leakage, E. On the right, a cutaway showing the parts of a typical single-hung window.

Comparing Original and Renovated Windows

We were not able to test most of the windows before and after renovation. Instead, we tested 64 "original" windows and 87 windows that had been renovated by contractors, and compared the results.

The windows varied widely in age and condition; a few were at least 100 years old. Many of the original windows had storm windows installed. Some renovated windows still had the original sash, while others had been retrofitted with a new sash. For the retained sashes, the contractors used a variety of weatherization and renovation methods; these are described below. The retrofitted windows had received either a new sash in the old jamb or a new vinyl or wood window insert (also known as a secondary frame) with a new sash. On some homes, the contractors had installed new storm windows.

Although the windows we tested varied in size and shape, we were able to make comparisons across sizes by normalizing the data to a typical window 36 inches wide by 60 inches high.

Measuring Infiltration and Thermal Losses

Window heat loss may be considered as a combination of thermal and infiltration (or leakage) losses. Thermal loss occurs when energy passes directly through the materials of the window. It includes radiation and convection to the interior surfaces of the window from the room; conduction through the materials of the window; and convection and radiation from the exterior surfaces of the windows to the outdoors. Infiltration losses are driven by wind and by differences between indoor and outdoor temperatures. They occur primarily through cracks in the sash, gaps between the sash and jamb, and gaps between the frame and rough opening (see Figure 1).

We calculated thermal losses using WINDOW 4.1, a computer model developed by Lawrence Berkeley National Laboratory's Building Technologies Program. We based our infiltration test method on ASTM E783-93,

Table 1. ELA (in In^2) for Baseline and Selected Renovated Windows

	Baseline Tight	Baseline Average	Baseline Loose	Replacement Sash	Vinyl Window Insert	Original Sash with Vinyl Jamb Liners
Number of windows tested	35	35	47	11	14	37
ELA sash	0.27	0.89	2.19	0.45	0.13	1.46
ELA rough opening*	0.59	0.59	0.59	0.30	0.16	0.39
ELA total	0.86	1.48	2.78	0.75	0.29	1.85

*Air leakage from the outside is assumed to be 30% of extraneous leakage. This is a simplifying assumption.

Table 2. Weatherization Methods and Materials at Sites Retaining Original Sash

Site	Number of windows	Method and Materials
A	7	Vinyl jamb liners
B	8	Vinyl jamb liners and silicone bulb weatherstripping (sill and head)
C	19	Vinyl jamb liners and silicone bulb weatherstripping (sill, head, and meeting rail)
D	3	Vinyl jamb liners; silicone bulb weatherstripping (sill, head, and meeting rail); replace single glass in original sash with double-pane insulating glass; new latch at meeting rail (Bi-Glass System)
E	3	Upper sash painted in place; zinc-ribbed weatherstripping on lower sash; V-strip weatherstripping at meeting rail; pulley seals; new storm windows
F	2	Upper sash painted in place; bronze V-strip weatherstripping on lower sash, meeting rail, and sill junction; existing storm windows; no locking mechanism
G	1	Weatherstripping between sash face and parting bead; V-strip weatherstripping at sill, head, and meeting rail

performing two air leakage tests on each window. We constructed a simple measurement device around the windows by taping a plastic sheet onto the interior trim and attaching an air hose, blower, and pressure tap. First, to test total leakage, we drew air through the window using the blower and measured the flow rate, in ft^3 per minute (CFM), at various pressure differentials across the plastic sheet. Then, to test extraneous leakage, we attached a second plastic sheet to the exterior trim of the window and repeated the test. By subtracting the value obtained in the second test from that obtained in the first, we were able to estimate sash leakage.

Some building designers think of window infiltration only in terms of sash leakage. But significant leakage can also occur between the window frame and the rough opening. (Note that window manufacturers report only sash leakage in product data.) To estimate how much rough opening leakage contributes to total window infiltration, we measured the temperature of the indoor air, the outdoor air, and the air being drawn through the window during 33 of the extraneous leakage tests.

We found that, on average, the air drawn through the windows in the study was approximately 30% cooler than the indoor air. Based on this difference, we assumed that approximately 30% of the extraneous leakage was outdoor air coming through the rough opening. We thus estimated total infiltration as sash leakage plus 30% of extraneous leakage. While this method was not very precise, it did allow us to estimate the relative contribution of rough opening leakage to heating load.

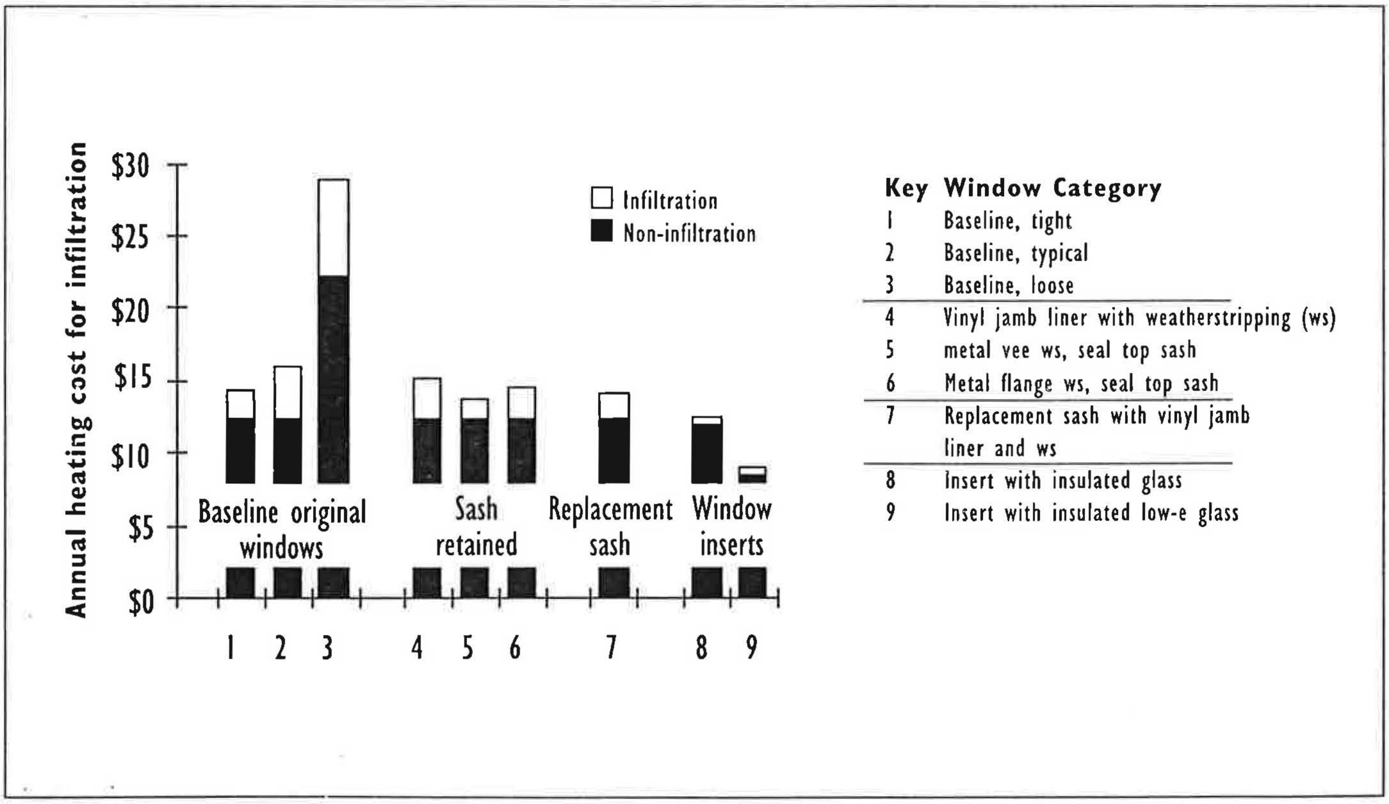


Figure 2. First year heating cost per window, pre- and post-treatment.

Surveying the Size of the Hole

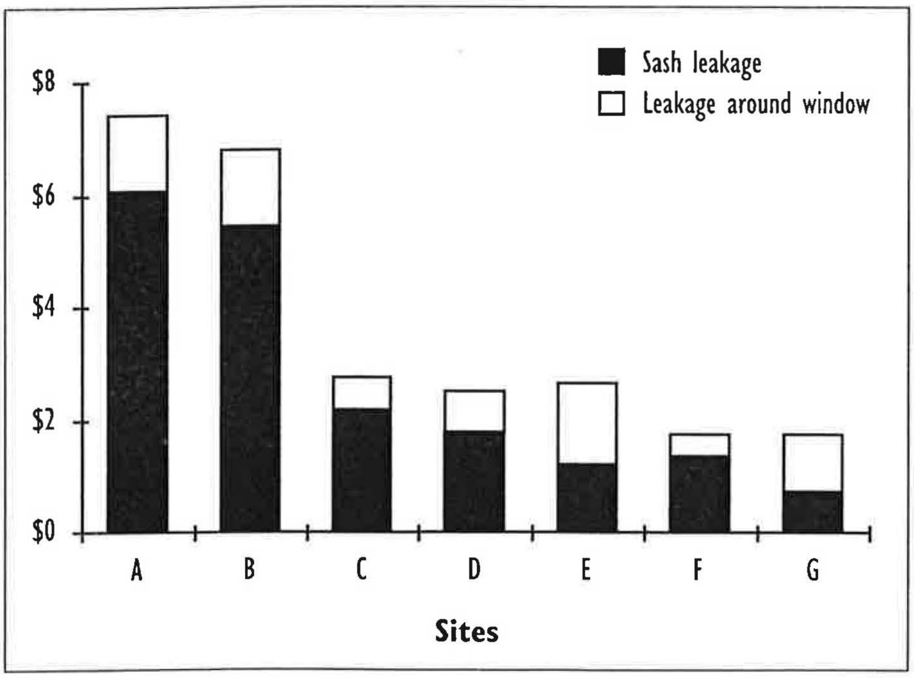
Using the results of the leakage tests, we calculated equivalent leakage areas (ELA) for both the original and the renovated windows. ELA is the area of a single round hole with a leakage rate equal to that of the aggregate of the leakage sites for a given window.

Air leakage rates of the original windows varied widely, reflecting the wide variation in the condition of the windows. We derived three baseline ELA values—typical, tight, and loose—for use in the comparison with the renovated and retrofitted windows. The loose baseline value was the mean leakage value of all the original windows without storm windows. The typical baseline value was the mean leakage value of all original windows that had storm windows in

Table 3. Renovated Windows Annual Heating Savings and Renovation Costs per Window

Renovation		Cost	Cost with Lead Abatement	Annual Savings (Tight)	Annual Savings (Typical)	Annual Savings (Loose)
Retain sash:						
	Vinyl jamb liner	$175	$300	none	$0.80	$14
	Weatherstripping	75	200	$0.20	1.70	15
Replace sash:						
	Single-glass sash	200	200	0.30	1.80	15
	Window inserts	250–500	200–500	1.90	3.40	16
	Low-e, double-glaze inserts	250–550	250–550	5.30	6.80	20
Storm Windows	New exterior	100	225	1.00	2.50	16
	New interior	115	240	1.30	2.80	16
	Interior low-e	155	280	4.70	6.20	19

Note: Costs for inserts varied with the material, which ranged from medium-cost vinyl to high-quality wood. Full-sash lead abatement adds $125 to other rehab costs. Savings were based on 7,744 degree-days and oil heat at 90¢/gallon with 75% overall heating season efficiency. Note that the samples of most windows tested were very small. Cost estimates for window upgrades were based on interviews with housing developers and/or builders. Estimates were normalized to a $20-per-hour labor rate, and included contractor markup.



KATHERINE FALK

Figure 3. First year heating costs, infiltration only, renovations retaining sash.

Getting the Lead Out of Windows

Flaking paint and paint dust from old windows is a potential source of lead hazard. To eliminate the hazard of lead paint you can either remove the paint or remove the window. Deciding which to do, of course, depends on cost and, in the case of historic buildings, the desire to preserve the window material.

Human exposure to lead from windows can occur in three basic ways: from lead dust that forms by paint abrasion in friction areas; from peeling and flaking on frame or sash; or by the fumes, chips, or dust generated during removal.

Several methods of paint removal exist; wet scraping and chemical removal are the preferred choices because they have less potential for generating airborne lead dust. Abrasive dry sanding and dry scraping create dust and should be avoided.

Wet scraping involves misting the surface with water, then hand scraping the surface to bare wood. Chemical stripping can be hazardous and is best done by a professional off-site. Generally, the glass is removed and the sash is dipped in a chemical bath or coated with a gel solution. The chemicals are caustic, and the resulting slurry is a hazardous waste.

Sometimes the jambs can simply be covered and not stripped. Vinyl jamb liners, which often include a spring balance system, are a popular choice and effective if properly installed. Other options for covering a painted (or unpainted) surface include aluminum coil stock, vinyl, and even duct tape, all of which have been used to create a smooth, cleanable surface in the window well, although preservationists have voiced concern over the potential moisture problems that could develop in a window well covered in impermeable material.

If a window is too far gone to justify repair, or if repair is too costly, replacement "in-kind" windows can be installed. The rule of thumb in Vermont is if 75% of a home's windows are in poor condition, then they all should be replaced. Otherwise, a combination of repair and replacement may be appropriate.

—Nancy Boone

Nancy Boone is State Architectural Historian of the Division for Historic Preservation in Montpelier, Vermont.

place. The tight baseline value was set at one standard deviation lower than the typical baseline value.

Table 1 is a summary of the ELAs for the original and renovated windows. The vinyl window insert was clearly the tightest option, having one-fifth the leakage of the baseline average.

Tightening Up with the Original Sash

For those houses where the sash was retained rather than replaced, we found that contractors used a variety of methods and materials to tighten the sashes. These methods and materials are summarized in Table 2.

Table 4. Annual Heating Cost for Upgrades that Include Replacing the Original Sash

Upgrade Description	Non-Infiltration Heating Cost	Infiltration Heating Cost	Total Heating Cost
Vinyl window insert	$12	$0.37	$12
Wood window insert	12	0.70	13
Sash & storm	12	1.68	14
Sash & storm (poor fit)	12	4.83	17
Insulated glass sash	12	0.60	13
Insulated low-e sash	8	0.60	9

Note: Savings were based on 7,744 degree-days and oil heat at 90¢/gal with 75% overall heating season efficiency. We did not observe the use of low-e glass in the field and calculated the thermal loss for the low-e retrofit. We estimated the added savings of low-e glass over other sash replacement strategies at $3.40 per year.

Comparing Costs and Savings

Having determined the ELAs, we then analyzed the impacts of the renovations and retrofits on energy savings. Figure 2 compares the infiltration and thermal loss heating costs of the baseline, renovated sash, and retrofitted windows. As expected, the results confirm that the largest energy savings came from tightening the loosest windows. However, the chart also shows that, except in the case of low-E glass window inserts, the difference in heating costs for the renovated sash and retrofitted windows was not great. Compared to the loose baseline, savings for the renovated windows ranged from $14 to $20 annually per window (3%–20% rate of return), while compared to the typical baseline, savings ranged from $1 to $7 annually (less than 1%–4% rate of return). Note that these annual returns actually reflect the first-year savings.

Lead Abatement

The problem of lead paint often arises when dealing with old windows. As shown in Table 3, lead abatement can add significantly to renovation costs (see "Getting the Lead Out"). For example, weatherizing a loose baseline window with weatherstripping, sealing the top sash, and rehabbing an existing storm costs $75 if lead abatement is not needed. At the annual savings rate of $15, this represents an annual rate of return of 20%. But when lead abatement is needed, the cost jumps to $200, which approaches the cost of replacing the sash.

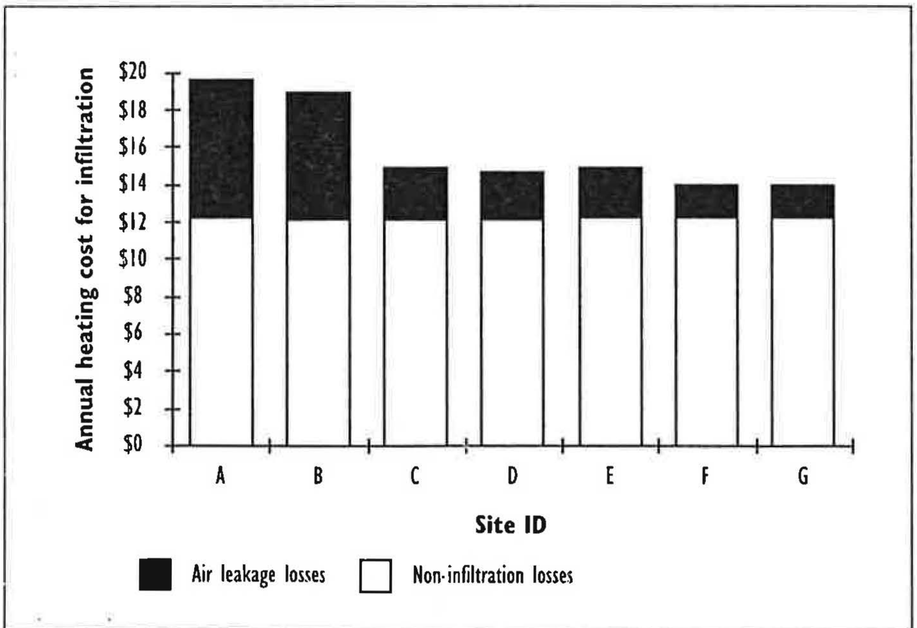


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Figure 4. Total first year heating cost, renovations retaining sash.

Storm Windows

Table 3 also shows the costs and savings associated with adding storm windows. A new exterior storm window added to a loose baseline window has a first-year savings of $16 at a cost of $100 (excluding lead abatement), or a 16% annual rate of return. Adding a low-e interior storm to a loose window saves $19 at a cost of $155, a 12% annual rate of return.

Figure 3 shows first-year heating costs due to air leakage only. The variation in the cost of air leakage in the first four columns suggests variability in workmanship in installing the jamb liners. Also, windows where the jamb was out of square had the poorest seal.

Sites C and D both incorporated weatherstripping at the meeting rail but the much lower leakage rates should not be attributed to that difference alone. Jamb liners require that the sash be fitted precisely to the liner and to the jamb to prevent leakage between the jamb and the jamb liner and between the liner and the sash.

The strategy used at site E resulted in quite low sash leakage. However, the total leakage was approximately the same as that at sites C and D, due to high leakage through the rough opening. Similarly, even though site G had a very low sash leakage, performance was undermined by the rough-opening leakage.

Is a New Sash Worth It?

Figure 4 compares the associated heating costs for infiltration and thermal losses for windows that retained the original sash. The chart shows that, compared to the thermal losses, infiltration accounted for a small part of the total heating cost, regardless of the strategy used.

Table 4 lists the heating costs for windows with new sashes or window inserts. With the exception of the low-e sash and the poorly fitted sash, the total heating costs were very similar, ranging from $12 to $14.

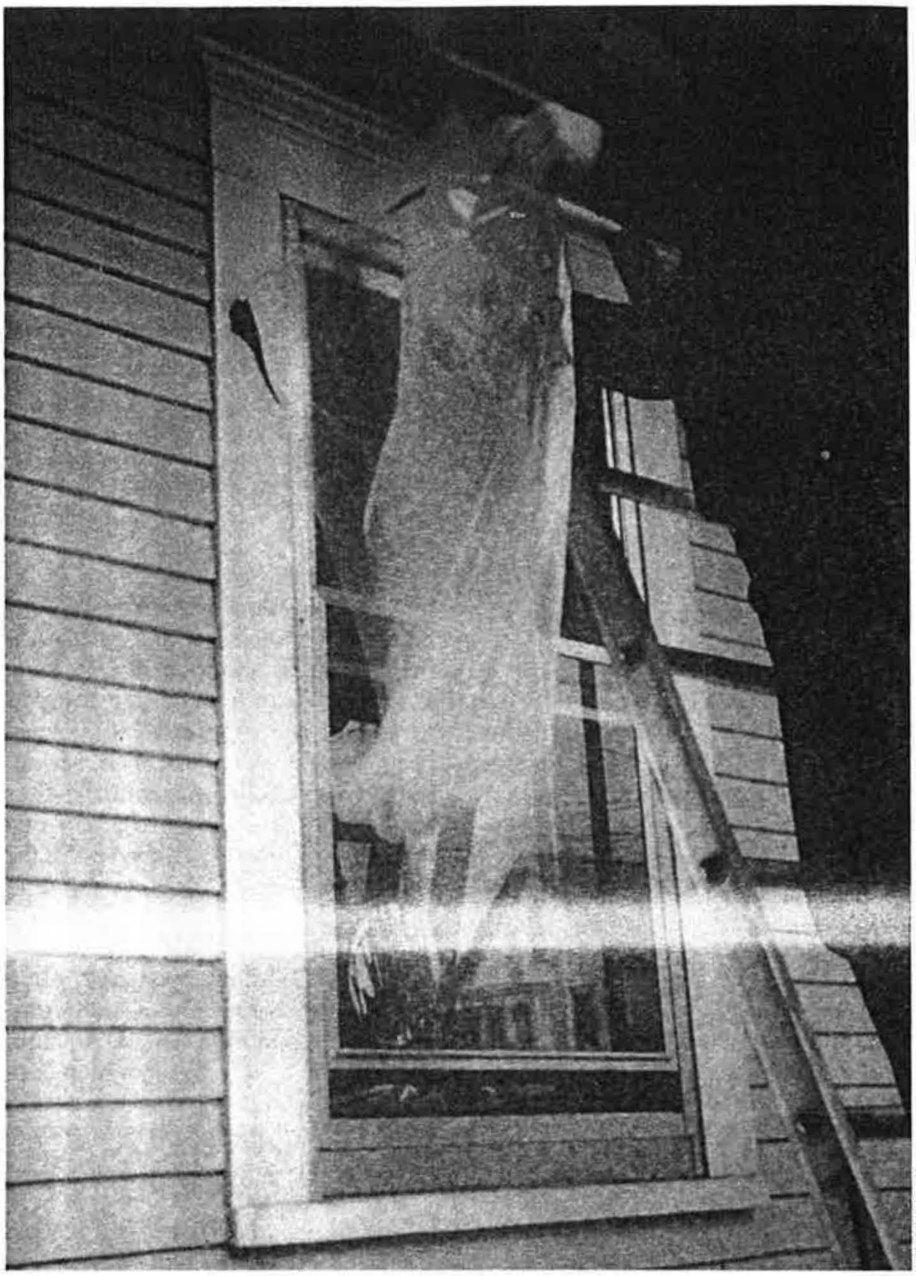
Preservationists Take Heart

Our study of old windows showed that the energy savings are similar for a variety of retrofit and replacement strategies. Rates of return on investment for energy improvements are quite low when starting with typical or tight windows with storms in place, but are significantly higher when renovating loose windows with no storm.

The difference in annual energy savings between renovating an old sash and replacing it with a new one was very small—retrofits saved only a few dollars.

For preservations, the good news is that with a proper choice of renovation strategy and good workmanship, historic sashes can be almost as energy-efficient as replacements. Window renovators and homeowners can give more weight to comfort, maintenance, lead abatement, egress requirements, durability, ease of operation—and historical value—without sacrificing energy savings. For those of us who work with old windows, this is very good news indeed.

Andrew M. Shapiro is an energy engineer with the Vermont Energy Investment Corporation in Burlington, Vermont. Brad James is a master's degree candidate at the University of Vermont. S. Flanders of the U.S. Army Cold Regions Research and Engineering Laboratory assisted with project oversight.



Brad James, who worked on much of the testing and analytic work for this study, covers a window with plastic in preparation for the extraneous leakage test.

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