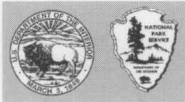


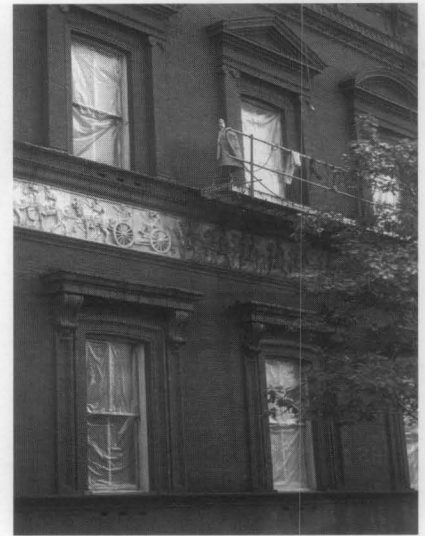
# 1 PRESERVATION BRIEFS

## Assessing Cleaning and Water-Repellent Treatments for Historic Masonry Buildings

Robert C. Mack, AIA  
Anne Grimmer



U.S. Department of the Interior  
National Park Service  
Cultural Resources  
Heritage Preservation Services



Inappropriate cleaning and coating treatments are a major cause of damage to historic masonry buildings. While either or both treatments may be appropriate in some cases, they can be very destructive to historic masonry if they are not selected carefully. Historic masonry, as considered here, includes stone, brick, architectural terra cotta, cast stone, concrete and concrete block. It is frequently cleaned because cleaning is equated with improvement. Cleaning may sometimes be followed by the application of a water-repellent coating. However, unless these procedures are carried out under the guidance and supervision of an architectural conservator, they may result in irrevocable damage to the historic resource.

The purpose of this Brief is to provide information on the variety of cleaning methods and materials that are available for use on the *exterior* of historic masonry buildings, and to provide guidance in selecting the most appropriate method or combination of methods. The difference between

water-repellent coatings and waterproof coatings is explained, and the purpose of each, the suitability of their application to historic masonry buildings, and the possible consequences of their inappropriate use are discussed.

The Brief is intended to help develop sensitivity to the qualities of historic masonry that makes it so special, and to assist historic building owners and property managers in working cooperatively with architects, architectural conservators and contractors (Fig. 1). Although specifically intended for historic buildings, the information is applicable to all masonry buildings. This publication updates and expands *Preservation Brief 1: The Cleaning and Waterproof Coating of Masonry Buildings*. The Brief is not meant to be a cleaning manual or a guide for preparing specifications. Rather, it provides general information to raise awareness of the many factors involved in selecting cleaning and water-repellent treatments for historic masonry buildings.



Figure 1. Low-to medium-pressure steam (hot-pressurized water washing), is being used to clean the exterior of the U.S. Tariff Commission Building, the first marble building constructed in Washington, D.C., in 1839. This method was selected by an architectural conservator as the "gentlest means possible" to clean the marble. Steam can soften heavy soiling deposits such as those on the cornice and column capitals, and facilitate easy removal. Note how these deposits have been removed from the right side of the cornice which has already been cleaned.

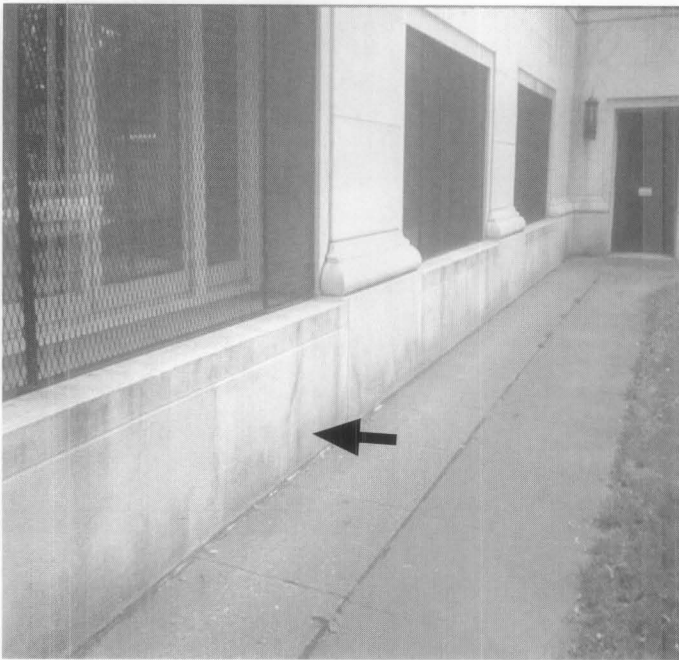


Figure 2. Biological growth as shown on this marble foundation can usually be removed using a low-pressure water wash, possibly with a non-ionic detergent added to it, and scrubbing with a natural or synthetic bristle brush.



Figure 3. This small test area has revealed a red brick patch that does not match the original beige brick. This may explain why the building was painted, and may suggest to the owner that it may be preferable to keep it painted.

## Preparing for a Cleaning Project

**Reasons for cleaning.** First, it is important to determine whether it is appropriate to clean the masonry. The objective of cleaning a historic masonry building must be considered carefully before arriving at a decision to clean. There are several major reasons for cleaning a historic masonry building: **improve the appearance of the building** by removing unattractive dirt or soiling materials, or non-historic paint from the masonry; **retard deterioration** by removing soiling materials that may be damaging the masonry; or **provide a clean surface** to accurately match repointing mortars or patching compounds, or to conduct a condition survey of the masonry.

**Identify what is to be removed.** The general nature and source of dirt or soiling material on a building must be identified to remove it in the *gentlest means possible* — that is, in the most effective, yet least harmful, manner. Soot and smoke, for example, require a different cleaning agent to remove than oil stains or metallic stains. Other common cleaning problems include biological growth such as mold or mildew, and organic matter such as the tendrils left on masonry after removal of ivy (Fig. 2).

**Consider the historic appearance of the building.** If the proposed cleaning is to remove paint, it is important in each case to learn whether or not unpainted masonry is historically appropriate. And, it is necessary to consider why the building was painted (Fig. 3). Was it to cover bad repointing or unmatched repairs? Was the building painted to protect soft brick or to conceal deteriorating stone? Or, was painted masonry simply a fashionable

treatment in a particular historic period? Many buildings were painted at the time of construction or shortly thereafter; retention of the paint, therefore, may be more appropriate historically than removing it. And, if the building appears to have been painted for a long time, it is also important to think about whether the paint is part of the character of the historic building and if it has acquired significance over time.

**Consider the practicalities of cleaning or paint removal.** Some gypsum or sulfate crusts may have become integral with the stone and, if cleaning could result in removing some of the stone surface, it may be preferable not to clean. Even where unpainted masonry is appropriate, the retention of the paint may be more practical than removal in terms of long range preservation of the masonry. In some cases, however, removal of the paint may be desirable. For example, the old paint layers may have built up to such an extent that removal is necessary to ensure a sound surface to which the new paint will adhere.

**Study the masonry.** Although not always necessary, in some instances it can be beneficial to have the coating or paint type, color, and layering on the masonry researched before attempting its removal. Analysis of the nature of the soiling or of the paint to be removed from the masonry, as well as guidance on the appropriate cleaning method, may be provided by professional consultants, including architectural conservators, conservation scientists and preservation architects. The State Historic Preservation Office (SHPO), local historic district commissions, architectural review boards and preservation-oriented websites may also be able to supply useful information on masonry cleaning techniques.

## Understanding the Building Materials

The construction of the building must be considered when developing a cleaning program because inappropriate cleaning can have a deleterious effect on the masonry as well as on other building materials. The masonry material or materials must be correctly identified. It is sometimes difficult to distinguish one type of stone from another; for example, certain sandstones can be easily confused with limestones. Or, what appears to be natural stone may not be stone at all, but cast stone or concrete. Historically, cast stone and architectural terra cotta were frequently used in combination with natural stone, especially for trim elements or on upper stories of a building where, from a distance, these substitute materials looked like real stone (Fig. 4). Other features on historic buildings that appear to be stone, such as decorative cornices, entablatures and window hoods, may not even be masonry, but metal.

**Identify prior treatments.** Previous treatments of the building and its surroundings should be researched and building maintenance records should be obtained, if available. Sometimes if streaked or spotty areas do not seem to get cleaner following an initial cleaning, closer inspection and analysis may be warranted. The discoloration may turn out not to be dirt but the remnant of a water-repellent coating applied long ago which has darkened the surface of the masonry over time (Fig. 5). Successful removal may require testing several cleaning agents to find something that will dissolve and remove the coating. Complete removal may not always be possible. Repairs may have been stained to match a dirty building, and cleaning may make these differences apparent. De-icing salts used near the building that have dissolved can



Figure 4. The foundation of this brick building is limestone, but the decorative trim above is architectural terra cotta intended to simulate stone.



Figure 5. Repeated water washing did not remove the staining inside this limestone porte cochere. Upon closer examination, it was determined to be a water-repellent coating that had been applied many years earlier. An alkaline cleaner may be effective in removing it.

migrate into the masonry. Cleaning may draw the salts to the surface, where they will appear as efflorescence (a powdery, white substance), which may require a second treatment to be removed. Allowances for dealing with such unknown factors, any of which can be a potential problem, should be included when investigating cleaning methods and materials. Just as more than one kind of masonry on a historic building may necessitate multiple cleaning approaches, unknown conditions that are encountered may also require additional cleaning treatments.

**Choose the appropriate cleaner.** The importance of testing cleaning methods and materials cannot be over emphasized. Applying the wrong cleaning agents to historic masonry can have disastrous results. Acidic cleaners can be extremely damaging to acid-sensitive stones, such as marble and limestone, resulting in etching and dissolution of these stones. Other kinds of masonry can also be damaged by incompatible cleaning agents, or even by cleaning agents that are usually compatible. There are also numerous kinds of sandstone, each with a considerably different geological composition. While an acid-based cleaner may be safely used on some sandstones, others are acid-sensitive and can be severely etched or dissolved by an acid cleaner. Some sandstones contain water-soluble minerals and can be eroded by water cleaning. And, even if the stone type is correctly identified, stones, as well as some bricks, may contain unexpected impurities, such as iron particles, that may react negatively with a particular cleaning agent and result in staining. Thorough understanding of the physical and chemical properties of the masonry will help avoid the inadvertent selection of damaging cleaning agents.

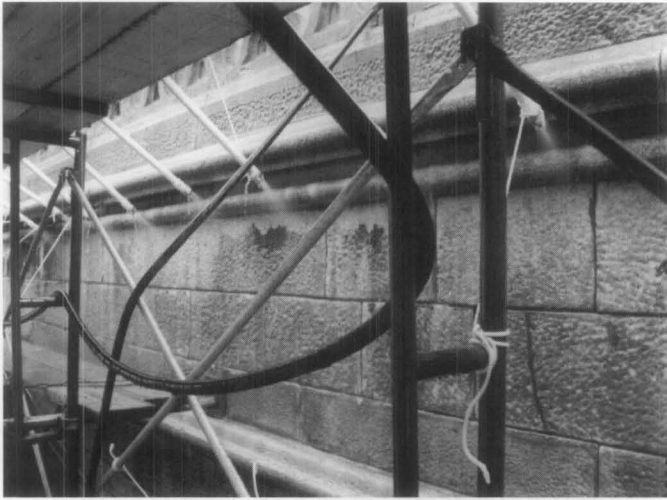


Figure 6. Timed water soaking can be very effective for cleaning limestone and marble as shown here at the Marble Collegiate Church in New York City. In this case, a twelve-hour water soak using a multi-nozzle manifold was followed by a final water rinse. Photo: Diane S. Kaese, Wiss, Janney, Elstner Associates, Inc., N.Y., N.Y.

Other building materials also may be affected by the cleaning process. Some chemicals, for example, may have a corrosive effect on paint or glass. The portions of building elements most vulnerable to deterioration may not be visible, such as embedded ends of iron window bars. Other totally unseen items, such as iron cramps or ties which hold the masonry to the structural frame, also may be subject to corrosion from the use of chemicals or even from plain water. The only way to prevent problems in these cases is to study the building construction in detail and evaluate proposed cleaning methods with this information in mind. However, due to the very likely possibility of encountering unknown factors, any cleaning project involving historic masonry should be viewed as unique to that particular building.

## Cleaning Methods and Materials

Masonry cleaning methods generally are divided into three major groups: water, chemical, and abrasive. *Water methods* soften the dirt or soiling material and rinse the deposits from the masonry surface. *Chemical cleaners* react with dirt, soiling material or paint to effect their removal, after which the cleaning effluent is rinsed off the masonry surface with water. *Abrasive methods* include blasting with grit, and the use of grinders and sanding discs, all of which mechanically remove the dirt, soiling material or paint (and, usually, some of the masonry surface). Abrasive cleaning is also often followed with a water rinse. *Laser cleaning*, although not discussed here in detail, is another technique that is used sometimes by conservators to clean small areas of historic masonry. It can be quite effective for cleaning limited areas, but it is expensive and generally not practical for most historic masonry cleaning projects.

Although it may seem contrary to common sense, masonry cleaning projects should be carried out starting at the

bottom and proceeding to the top of the building always keeping all surfaces wet below the area being cleaned. The rationale for this approach is based on the principle that dirty water or cleaning effluent dripping from cleaning in progress above will leave streaks on a dirty surface but will not streak a clean surface as long as it is kept wet and rinsed frequently.

## Water Cleaning

Water cleaning methods are generally the *gentlest means possible*, and they can be used safely to remove dirt from all types of historic masonry.\* There are essentially four kinds of water-based methods: soaking; pressure water washing; water washing supplemented with non-ionic detergent; and steam, or hot-pressurized water cleaning. Once water cleaning has been completed, it is often necessary to follow up with a water rinse to wash off the loosened soiling material from the masonry.

**Soaking.** Prolonged spraying or misting with water is particularly effective for cleaning limestone and marble. It is also a good method for removing heavy accumulations of soot, sulfate crusts or gypsum crusts that tend to form in protected areas of a building not regularly washed by rain. Water is distributed to lengths of punctured hose or pipe with non-ferrous fittings hung from moveable scaffolding or a swing stage that continuously mists the surface of the masonry with a very fine spray (Fig. 6). A timed on-off spray is another approach to using this cleaning technique. After one area has been cleaned, the apparatus is moved on to another. Soaking is often used in combination with water washing and is also followed by a final water rinse. Soaking is a very slow method — it may take several days or a week—but it is a very gentle method to use on historic masonry.

**Water Washing.** Washing with low-pressure or medium-pressure water is probably one of the most commonly used methods for removing dirt or other pollutant soiling from historic masonry buildings (Fig. 7). Starting with a very low pressure (100 psi or below), even using a garden hose, and progressing as needed to slightly higher pressure —generally no higher than 300-400 psi—is always the recommended way to begin. Scrubbing with natural bristle or synthetic bristle brushes—never metal which can abrade the surface and leave metal particles that can stain the masonry—can help in cleaning areas of the masonry that are especially dirty.

**Water Washing with Detergents.** Non-ionic detergents—which are not the same as soaps—are synthetic organic compounds that are especially effective in removing oily soil. (Examples of some of the numerous proprietary non-ionic detergents include Igepal by GAF, Tergitol by Union Carbide and Triton by Rohm & Haas.) Thus, the addition of a non-ionic detergent, or surfactant, to a low- or medium-pressure water wash can be a useful aid in the cleaning

\*Water cleaning methods may not be appropriate to use on some badly deteriorated masonry because water may exacerbate the deterioration, or on gypsum or alabaster which are very soluble in water.

process. (A non-ionic detergent, unlike most household detergents, does not leave a solid, visible residue on the masonry.) Adding a non-ionic detergent and scrubbing with a natural bristle or synthetic bristle brush can facilitate cleaning textured or intricately carved masonry. This should be followed with a final water rinse.

**Steam/Hot-Pressurized Water Cleaning.** Steam cleaning is actually low-pressure hot water washing because the steam condenses almost immediately upon leaving the hose. This is a gentle and effective method for cleaning stone and particularly for acid-sensitive stones. Steam can be especially useful in removing built-up soiling deposits and dried-up plant materials, such as ivy disks and tendrils. It can also be an efficient means of cleaning carved stone details and, because it does not generate a lot of liquid water, it can sometimes be appropriate to use for cleaning interior masonry (Figs. 8-9).

**Potential hazards of water cleaning.** Despite the fact that water-based methods are generally the most gentle, even they can be damaging to historic masonry. Before beginning a water cleaning project, it is important to make sure that all mortar joints are sound and that the building is watertight. Otherwise water can seep through the walls to the interior, resulting in rusting metal anchors and stained and ruined plaster.

Some water supplies may contain traces of iron and copper which may cause masonry to discolor. Adding a chelating or complexing agent to the water, such as EDTA (ethylene diamine tetra-acetic acid), which inactivates other metallic ions, as well as softens minerals and water hardness, will help prevent staining on light-colored masonry.

Any cleaning method involving water should never be done in cold weather or if there is any likelihood of frost or freezing because water within the masonry can freeze, causing spalling and cracking. Since a masonry wall may take over a week to dry after cleaning, no water cleaning should be permitted for several days prior to the first average frost date, or even earlier if local forecasts predict cold weather.

Most essential of all, it is important to be aware that using water at too high a pressure, a practice common to "power washing" and "water blasting", is very abrasive and can easily etch marble and other soft stones, as well as some types of brick (Figs. 10-11). In addition, the distance of the nozzle from the masonry surface and the type of nozzle, as well as gallons per minute (gpm), are also important variables in a water cleaning process that can have a significant impact on the outcome of the project. This is why it is imperative that the cleaning be closely monitored to ensure that the cleaning operators do not raise the pressure or bring the nozzle too close to the masonry in an effort to "speed up" the process. The appearance of grains of stone or sand in the cleaning effluent on the ground is an indication that the water pressure may be too high.



Figure 7. Glazed architectural terra cotta often may be cleaned successfully with a low-pressure water wash and hand scrubbing supplemented, if necessary, with a non-ionic detergent. Photo: National Park Service Files.

## Chemical Cleaning

Chemical cleaners, generally in the form of proprietary products, are another material frequently used to clean historic masonry. They can remove dirt, as well as paint and other coatings, metallic and plant stains, and graffiti. Chemical cleaners used to remove dirt and soiling include **acids, alkalis** and **organic compounds**. Acidic cleaners, of course, should not be used on masonry that is acid sensitive. Paint removers are **alkaline**, based on **organic solvents** or other chemicals.

## Chemical Cleaners to Remove Dirt

Both alkaline and acidic cleaning treatments include the use of water. Both cleaners are also likely to contain surfactants (wetting agents), that facilitate the chemical reaction that removes the dirt. Generally, the masonry is wet first for both types of cleaners, then the chemical cleaner is sprayed on at very low pressure or brushed onto the surface. The cleaner is left to dwell on the masonry for an amount of time recommended by the product manufacturer or, preferably, determined by testing, and rinsed off with a low- or moderate-pressure cold, or sometimes hot, water wash. More than one application of the cleaner may be necessary, and it is always a good practice to test the product manufacturer's recommendations concerning dilution rates and dwell times. Because each cleaning situation is unique, dilution rates and dwell times can vary considerably. The masonry surface may be scrubbed lightly with natural or synthetic bristle brushes prior to rinsing. After rinsing, pH strips should be applied to the surface to ensure that the masonry has been neutralized completely.

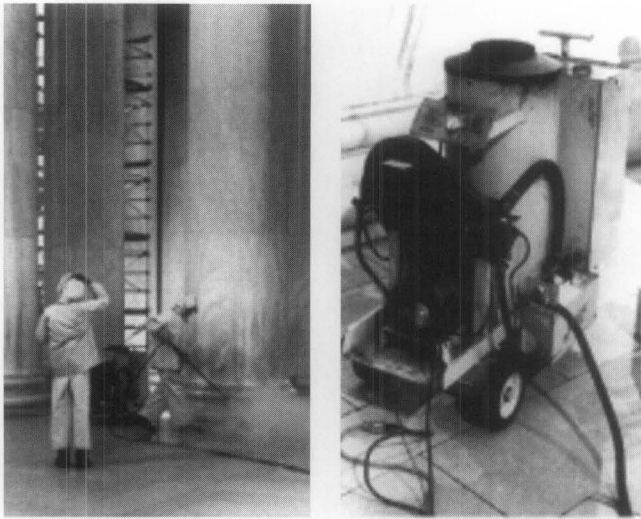


Figure 8. (Left) Low-pressure (under 100 psi) steam cleaning (hot-pressurized water washing), is part of the regular maintenance program at the Jefferson Memorial, Washington, D.C. The white marble interior of this open structure is subject to constant soiling by birds, insects and visitors. (Right) This portable steam cleaner enables prompt cleanup when necessary. Photos: National Park Service Files.

**Acidic Cleaners.** Acid-based cleaning products may be used on **non-acid sensitive** masonry, which generally includes: granite, most sandstones, slate, unglazed brick and unglazed architectural terra cotta, cast stone and concrete (Fig. 12). Most commercial acidic cleaners are composed primarily of hydrofluoric acid, and often include some phosphoric acid to prevent rust-like stains from developing on the masonry after the cleaning. Acid cleaners are applied to the pre-wet masonry which should be kept wet while the acid is allowed to "work", and then removed with a water wash.

**Alkaline Cleaners.** Alkaline cleaners should be used on **acid-sensitive** masonry, including: limestone, polished and unpolished marble, calcareous sandstone, glazed brick and glazed architectural terra cotta, and polished granite. (Alkaline cleaners may also be used sometimes on masonry materials that are not acid sensitive—after testing, of course

—but they may not be as effective as they are on acid-sensitive masonry.) Alkaline cleaning products consist primarily of two ingredients: a non-ionic detergent or surfactant; and an alkali, such as potassium hydroxide or ammonium hydroxide. Like acidic cleaners, alkaline products are usually applied to pre-wet masonry, allowed to dwell, and then rinsed off with water. (Longer dwell times may be necessary with alkaline cleaners than with acidic cleaners.) Two additional steps are required to remove alkaline cleaners after the initial rinse. First the masonry is given a slightly acidic wash—often with acetic acid—to neutralize it, and then it is rinsed again with water.

**Chemical Cleaners to Remove Paint and Other Coatings, Stains and Graffiti**

Removing paint and some other coatings, stains and graffiti can best be accomplished with alkaline paint removers, organic solvent paint removers, or other cleaning compounds. The removal of layers of paint from a masonry surface usually involves applying the remover either by brush, roller or spraying, followed by a thorough water wash. As with any chemical cleaning, the manufacturer's recommendations regarding application procedures should always be tested before beginning work.

**Alkaline Paint Removers.** These are usually of much the same composition as other alkaline cleaners, containing potassium or ammonium hydroxide, or trisodium phosphate. They are used to remove oil, latex and acrylic paints, and are effective for removing multiple layers of paint. Alkaline cleaners may also remove some acrylic, water-repellent coatings. As with other alkaline cleaners, both an acidic neutralizing wash and a final water rinse are generally required following the use of alkaline paint removers.

**Organic Solvent Paint Removers.** The formulation of organic solvent paint removers varies and may include a combination of solvents, including methylene chloride, methanol, acetone, xylene and toluene.

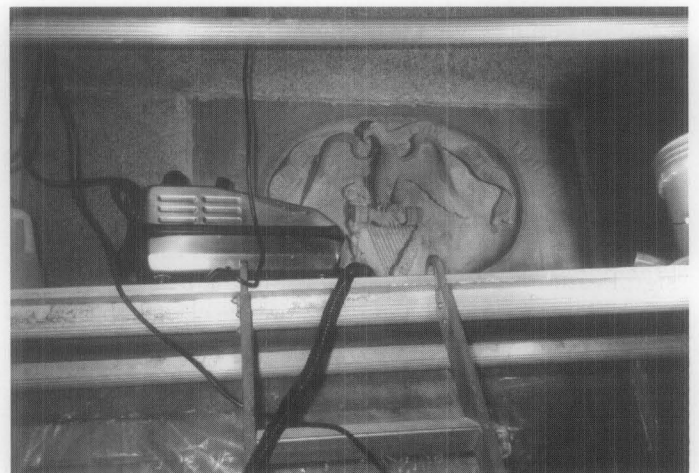


Figure 9. (Left) This small steam cleaner—the size of a vacuum cleaner—offers a very controlled and gentle means of cleaning limited, or hard-to-reach areas or carved stone details. (Right) It is particularly useful for interiors where it is important to keep moisture to a minimum, such as inside the Washington Monument, Washington, D.C., where it was used to clean the commemorative stones. Photos: Audrey T. Tepper.



Figure 10. High-pressure water washing too close to the surface has abraded and, consequently, marred the limestone on this early-20th century building.

**Other Paint Removers and Cleaners.** Other cleaning compounds that can be used to remove paint and some painted graffiti from historic masonry include paint removers based on N-methyl-2-pyrrolidone (NMP), or on petroleum-based compounds. Removing stains, whether they are industrial (smoke, soot, grease or tar), metallic (iron or copper), or biological (plant and fungal) in origin, depends on carefully matching the type of remover to the type of stain (Fig. 13). Successful removal of stains from historic masonry often requires the application of a number of different removers before the right one is found. The removal of layers of paint from a masonry surface is usually accomplished by applying the remover either by brush, roller or spraying, followed by a thorough water wash (Fig. 14).

**Potential hazards of chemical cleaning.** Since most chemical cleaning methods involve water, they have many of the potential problems of plain water cleaning. Like water methods, they should not be used in cold weather because of the possibility of freezing. Chemical cleaning should never be undertaken in temperatures below 40 degrees F (4 degrees C), and generally not below 50 degrees F. In addition, many chemical cleaners simply do not work in cold temperatures. Both acidic and alkaline cleaners can be dangerous to cleaning operators and, clearly, there are environmental concerns associated with the use of chemical cleaners.

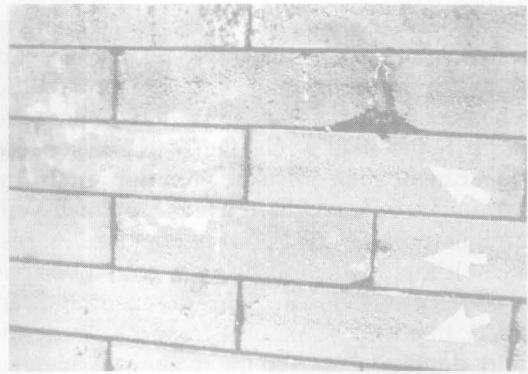


Figure 11. Rinsing with high-pressure water following chemical cleaning has left a horizontal line of abrasion across the bricks on this late-19th century row house.

If not carefully chosen, chemical cleaners can react adversely with many types of masonry. Obviously, acidic cleaners should not be used on acid-sensitive materials; however, it is not always clear exactly what the composition is of any stone or other masonry material. For this reason, testing the cleaner on an inconspicuous spot on the building is always necessary. While certain acid-based cleaners may be appropriate if used as directed on a particular type of masonry, if left too long or if not adequately rinsed from the masonry they can have a negative effect. For example, hydrofluoric acid can etch masonry leaving a hazy residue (whitish deposits of silica or calcium fluoride salts) on the surface. While this efflorescence may usually be removed by a second cleaning—although it is likely to be expensive and time-consuming—hydrofluoric acid can also leave calcium fluoride salts or a colloidal silica deposit on masonry which may be impossible to remove (Fig. 15). Other acids, particularly hydrochloric (muriatic) acid, which is very powerful, should not be used on historic masonry, because it can dissolve lime-based mortar, damage brick and some stones, and leave chloride deposits on the masonry.



Figure 12. A mild acidic cleaning agent is being used to clean this heavily soiled brick and granite building. Additional applications of the cleaner and hand-scrubbing, and even poulticing, may be necessary to remove the dark stains on the granite arches below. Photo: Sharon C. Park, FAIA.

Alkaline cleaners can stain sandstones that contain a ferrous compound. Before using an alkaline cleaner on sandstone it is always important to test it, since it may be difficult to know whether a particular sandstone may contain a ferrous compound. Some alkaline cleaners, such as **sodium hydroxide (caustic soda or lye)** and **ammonium bifluoride**, can also damage or leave disfiguring brownish-yellow stains and, in most cases, should not be used on historic masonry. Although alkaline cleaners will not etch a masonry surface as acids can, they are caustic and can burn the surface. In addition, alkaline cleaners can deposit potentially damaging salts in the masonry which can be difficult to rinse thoroughly.

### Abrasive and Mechanical Cleaning

Generally, abrasive cleaning methods are not appropriate for use on historic masonry buildings. Abrasive cleaning methods are just that—abrasive. Grit blasters, grinders, and sanding discs all operate by *abrading* the dirt or paint off the surface of the masonry, rather than *reacting* with the dirt and the masonry which is how water and chemical methods work. Since the abrasives do not differentiate between the dirt and the masonry, they can also remove the outer surface of the masonry at the same time, and result in permanently damaging the masonry. Brick, architectural terra cotta, soft stone, detailed carvings, and polished surfaces are especially susceptible to physical and aesthetic damage by abrasive methods. Brick and architectural terra cotta are fired products which have a smooth, glazed surface which can be removed by abrasive blasting or grinding (Figs. 18-19). Abrasively-cleaned masonry is damaged aesthetically as well as physically, and it has a rough surface which tends to hold dirt and the roughness will make future cleaning more difficult. Abrasive cleaning processes can also increase the likelihood of subsurface cracking of the masonry. Abrasion of carved details causes a rounding of sharp corners and other loss of delicate features, while abrasion of polished surfaces removes the polished finish of stone.

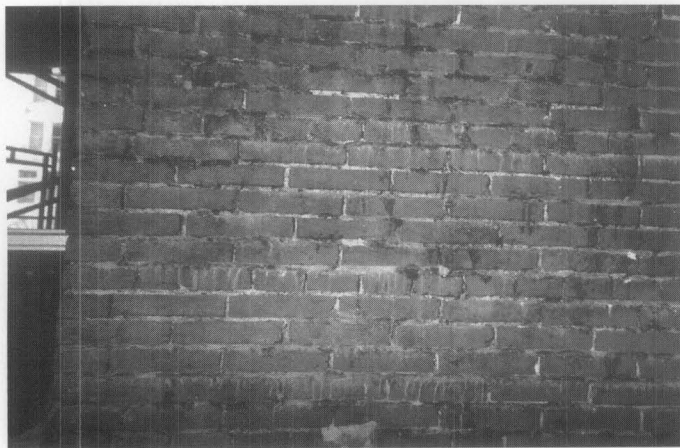


Figure 13. Sometimes it may be preferable to paint over a thick asphaltic coating rather than try to remove it, because it can be difficult to remove completely. However, in this case, many layers of asphaltic coating were removed through multiple applications of a heavy duty chemical cleaner. Each application of the cleaner was left to dwell following the manufacturer's recommendations, and then rinsed thoroughly. (As much as possible of the asphalt was first removed with wooden scrapers.) Although not all the asphalt was removed, this was determined to be an acceptable level of cleanliness for the project.



Figure 14. Chemical removal of paint from this brick building has revealed that the cornice and window hoods are metal rather than masonry.

Mortar joints, especially those with lime mortar, also can be eroded by abrasive or mechanical cleaning. In some cases, the damage may be visual, such as loss of joint detail or increased joint shadows. As mortar joints constitute a significant portion of the masonry surface (up to 20 per cent in a brick wall), this can result in the loss of a considerable amount of the historic fabric. Erosion of the mortar joints may also permit increased water penetration, which will likely necessitate repointing.

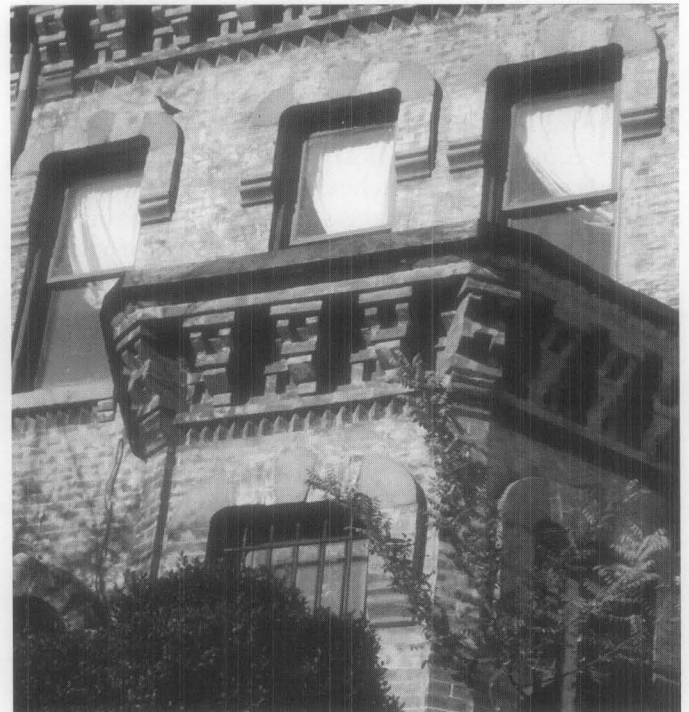


Figure 15. The whitish deposits left on the brick by a chemical paint remover may have resulted from inadequate rinsing or from the chemical being left on the surface too long and may be impossible to remove.



## Poulticing to Remove Stains and Graffiti

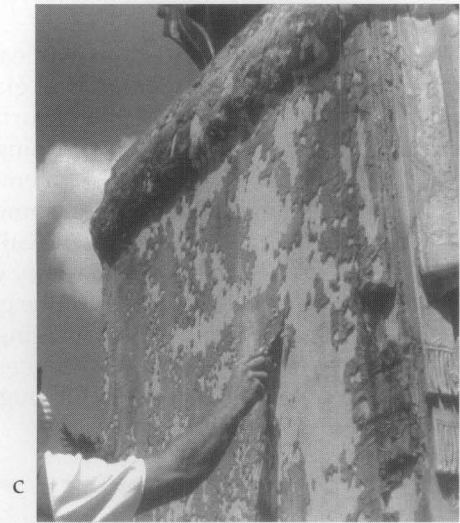


Figure 16. (a) The limestone base was heavily stained by runoff from the bronze statue above. (b) A poultice consisting of copper stain remover and ammonia mixed with fuller's earth was applied to the stone base and covered with plastic sheeting to keep it from drying out too quickly. (c) As the poultice dried, it pulled the stain out of the stone. (d) The poultice residue was removed carefully from the stone surface with wooden scrapers and the stone was rinsed with water. Photos: John Dugger.

Graffiti and stains, which have penetrated into the masonry, often are best removed by using a poultice. A poultice consists of an absorbent material or clay powder (such as kaolin or fuller's earth, or even shredded paper or paper towels), mixed with a liquid (solvent or other remover) to form a paste which is applied to the stain (Figs. 16-17). As it dries, the paste absorbs the staining material so that it is not redeposited on the masonry surface. Some commercial cleaning products and paint removers are specially formulated as a paste or gel that will cling to a vertical surface and remain moist for a longer period of time in order to prolong the action of the chemical on the stain. Pre-mixed poultices are also available as a paste or in powder form needing only the addition of the appropriate liquid. The masonry must be pre-wet before applying an alkaline cleaning agent, but not when using a solvent. Once the stain has been removed, the masonry must be rinsed thoroughly.



Figure 17. A poultice is being used to remove salts from the brownstone statuary on the facade of this late-19th century stone church. Photo: National Park Service Files.



Figure 18. The glazed bricks in the center of the pier were covered by a signboard that protected them from being damaged by the sandblasting which removed the glaze from the surrounding bricks.

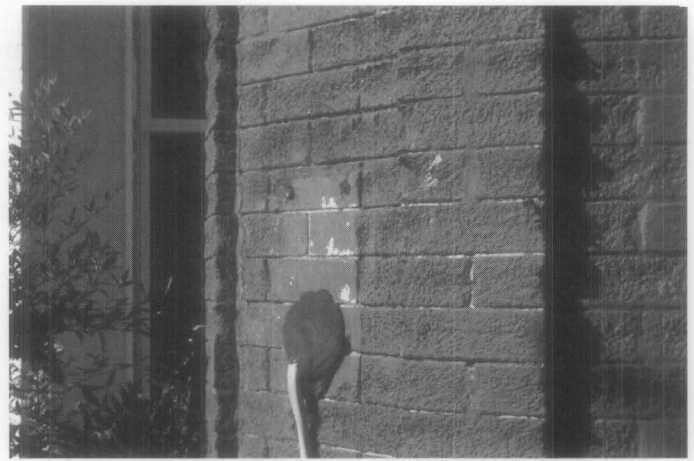


Figure 19. A comparison of undamaged bricks surrounding the electrical conduit with the rest of the brick facade emphasizes the severity of the erosion caused by sandblasting.

**Abrasive Blasting.** Blasting with abrasive grit or another abrasive material is the most frequently used abrasive method. *Sandblasting* is most commonly associated with abrasive cleaning. Finely ground silica or glass powder, glass beads, ground garnet, powdered walnut and other ground nut shells, grain hulls, aluminum oxide, plastic particles and even tiny pieces of sponge, are just a few of the other materials that have also been used for abrasive cleaning. Although abrasive blasting is not an appropriate method of cleaning historic masonry, it can be safely used to clean some materials. Finely-powdered walnut shells are commonly used for cleaning monumental bronze sculpture, and skilled conservators clean delicate museum objects and finely detailed, carved stone features with very small, micro-abrasive units using aluminum oxide.

A number of current approaches to abrasive blasting rely on materials that are not usually thought of as abrasive, and not as commonly associated with traditional abrasive grit cleaning. Some patented abrasive cleaning processes—one dry, one wet—use finely-ground glass powder intended to “erase” or remove dirt and surface soiling only, but not paint or stains (Fig. 20). Cleaning with baking soda (sodium bicarbonate) is another patented process. Baking soda blasting is being used in some communities as a means of quick graffiti removal. However, it should not be used on historic masonry which it can easily abrade and can permanently “etch” the graffiti into the stone; it can also leave potentially damaging salts in the stone which cannot be removed. Most of these abrasive grits may be used either dry or wet, although dry grit tends to be used more frequently.

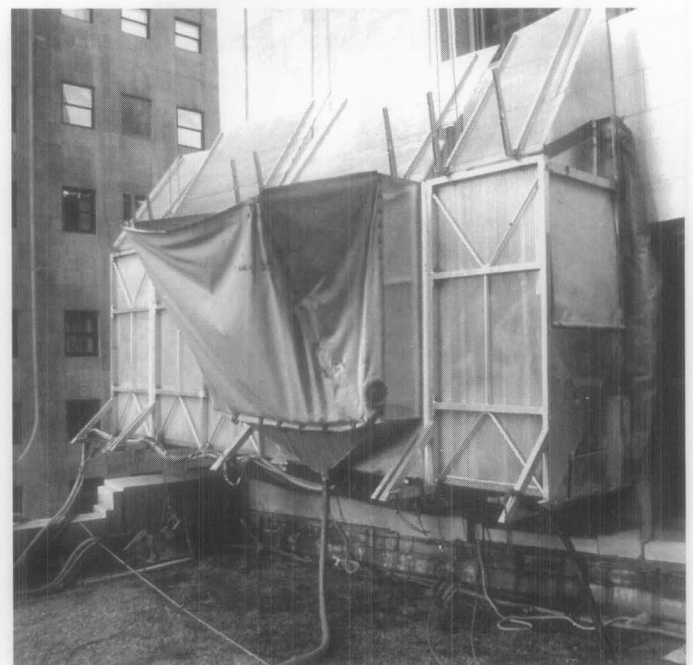
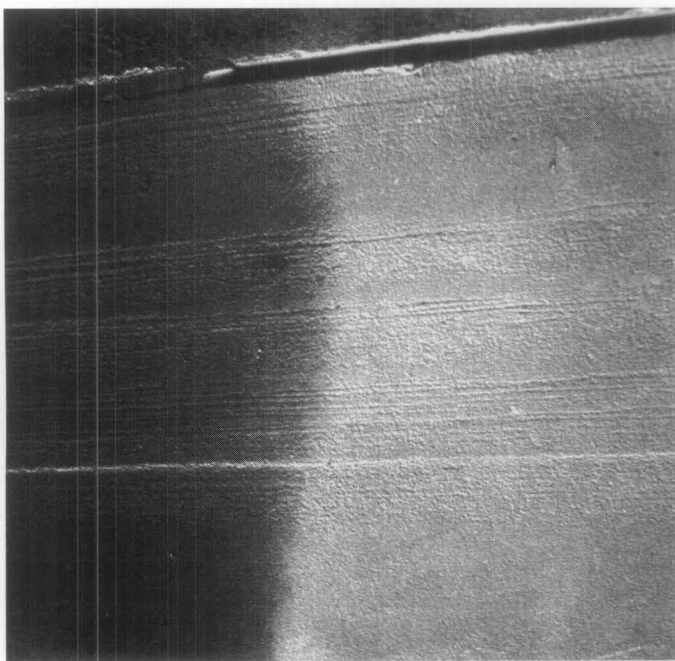


Figure 20. (Left) A comparison of the limestone surface of a 1920s office building before and after “cleaning” with a proprietary abrasive process using fine glass powder clearly shows the effectiveness of this method. But this is an abrasive technique and it has “cleaned” by removing part of the masonry surface with the dirt. Because it is abrasive, it is generally not recommended for large-scale cleaning of historic masonry, although it may be suitable to use in certain, very limited cases under controlled circumstances. (Right) A vacuum chamber where the used glass powder is collected for environmentally safe disposal is a unique feature of this particular process. The specially-trained operators in the chamber wear protective clothing, masks and breathing equipment. Photos: Tom Keohan.

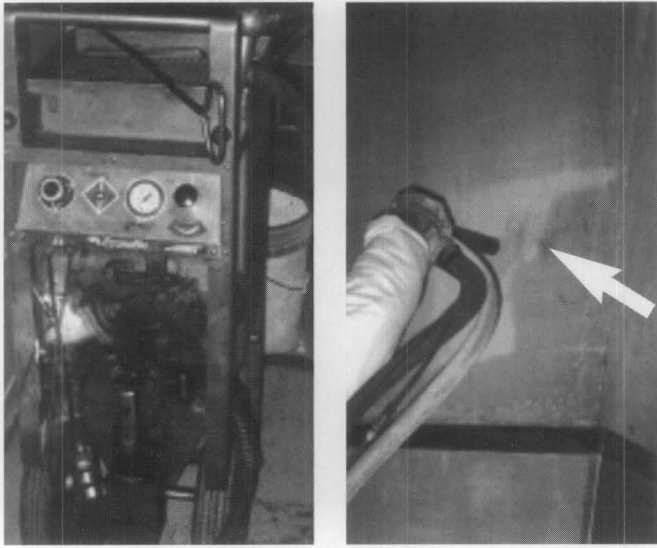


Figure 21. Low-pressure blasting with ice pellets or ice crystals (left) is an abrasive cleaning method that is sometimes recommended for use on interior masonry because it does not involve large amounts of water. However, like other abrasive materials, ice crystals "clean" by removing a portion of the masonry surface with the dirt, and may not remove some stains that have penetrated into the masonry without causing further abrasion (right). Photos: Audrey T. Tepper.

Ice particles, or pelletized dry ice (carbon dioxide or CO<sub>2</sub>), are another medium used as an abrasive cleaner (Fig. 21). This is also too abrasive to be used on most historic masonry, but it may have practical application for removing mastics or asphaltic coatings from some substrates.

Some of these processes are promoted as being more environmentally safe and not damaging to historic masonry buildings. However, it must be remembered that they are abrasive and that they "clean" by removing a small portion of the masonry surface, even though it may be only a minuscule portion. The fact that they are essentially abrasive treatments must always be taken into consideration when planning a masonry cleaning project. *In general, abrasive methods should not be used to clean historic masonry buildings.* In some, very limited instances, highly-controlled, gentle abrasive cleaning may be appropriate on selected, hard-to-clean areas of a historic masonry building if carried out under the watchful supervision of a professional conservator. But, abrasive cleaning should never be used on an entire building.

**Grinders and Sanding Disks.** Grinding the masonry surface with mechanical grinders and sanding disks is another means of abrasive cleaning that should not be used on historic masonry. Like abrasive blasting, grinders and disks do not really clean masonry but instead grind away and abrasively remove and, thus, damage the masonry surface itself rather than remove just the soiling material.

## Planning A Cleaning Project

Once the masonry and soiling material or paint have been identified, and the condition of the masonry has been evaluated, planning for the cleaning project can begin.

**Testing cleaning methods.** In order to determine the *gentlest means possible*, several cleaning methods or materials may have to be tested prior to selecting the best one to use on the building. Testing should always begin with the gentlest and least invasive method proceeding gradually, if necessary, to more complicated methods, or a combination of methods. All too often simple methods, such as low-pressure water wash, are not even considered, yet they frequently are effective, safe, and not expensive. Water of slightly higher pressure or with a non-ionic detergent additive also may be effective. It is worth repeating that these methods should always be tested prior to considering harsher methods; they are safer for the building and the environment, often safer for the applicator, and relatively inexpensive.

The level of cleanliness desired also should be determined prior to selection of a cleaning method. Obviously, the intent of cleaning is to remove most of the dirt, soiling material, stains, paint or other coating. A "brand new" appearance, however, may be inappropriate for an older building, and may require an overly harsh cleaning method to be achieved. When undertaking a cleaning project, it is important to be aware that some stains simply may not be removable. It may be wise, therefore, to agree upon a slightly lower level of cleanliness that will serve as the standard for the cleaning project. The precise amount of residual dirt considered acceptable may depend on the type of masonry, the type of soiling and difficulty of total removal, and local environmental conditions.

Cleaning tests should be carried out in an area of sufficient size to give a true indication of their effectiveness. It is preferable to conduct the test in an inconspicuous location on the building so that it will not be obvious if the test is not successful. A test area may be quite small to begin, sometimes as small as six square inches, and gradually may be increased in size as the most appropriate methods and cleaning agents are determined. Eventually the test area may be expanded to a square yard or more, and it should include several masonry units and mortar joints (Fig. 22). It should be remembered that a single building may have several types of masonry and that even similar materials may have different surface finishes. Each material and different finish should be tested separately. Cleaning tests should be evaluated only after the masonry has dried completely. *The results of the tests may indicate that several methods of cleaning should be used on a single building.*

When feasible, test areas should be allowed to weather for an extended period of time prior to final evaluation. A waiting period of a full year would be ideal in order to expose the test patch to a full range of seasons. If this is not possible, the test patch should weather for at least a month or two. For any building which is considered historically important, the delay is insignificant compared to the potential damage and disfigurement which may result from using an incompletely tested method. *The successfully cleaned test patch should be protected as it will serve as a standard against which the entire cleaning project will be measured.*

**Environmental considerations.** The potential effect of any method proposed for cleaning historic masonry should be evaluated carefully. Chemical cleaners and paint removers may damage trees, shrubs, grass, and plants. A plan must be provided for environmentally safe removal and disposal of the cleaning materials and the rinsing effluent before beginning the cleaning project. Authorities from the local regulatory agency – usually under the jurisdiction of the federal or state Environmental Protection Agency (EPA) should be consulted prior to beginning a cleaning project, especially if it involves anything more than plain water washing. This advance planning will ensure that the cleaning effluent or run-off, which is the combination of the cleaning agent and the substance removed from the masonry, is handled and disposed of in an environmentally sound and legal manner. Some alkaline and acidic cleaners can be neutralized so that they can be safely discharged into storm sewers. However, most solvent-based cleaners cannot be neutralized and are categorized as pollutants, and must be disposed of by a licensed transport, storage and disposal facility. Thus, it is always advisable to consult with the appropriate agencies before starting to clean to ensure that the project progresses smoothly and is not interrupted by a stop-work order because a required permit was not obtained in advance.

Vinyl guttering or polyethylene-lined troughs placed around the perimeter of the base of the building can serve to catch chemical cleaning waste as it is rinsed off the building. This will reduce the amount of chemicals entering and polluting the soil, and also will keep the cleaning waste contained until it can be removed safely. Some patented cleaning systems have developed special equipment to facilitate the containment and later disposal of cleaning waste.

Concern over the release of volatile organic compounds (VOCs) into the air has resulted in the manufacture of new, more environmentally responsible cleaners and paint removers, while some materials traditionally used in cleaning may no longer be available for these same reasons. Other health and safety concerns have created additional cleaning challenges, such as lead paint removal, which is likely to require special removal and disposal techniques.

Cleaning can also cause damage to non-masonry materials on a building, including glass, metal and wood. Thus, it is usually necessary to cover windows and doors, and other features that may be vulnerable to chemical cleaners. They should be covered with plastic or polyethylene, or a masking agent that is applied as a liquid which dries to form a thin protective film on glass, and is easily peeled off after the cleaning is finished. Wind drift, for example, can also damage other property by carrying cleaning chemicals onto nearby automobiles, resulting in etching of the glass or spotting of the paint finish. Similarly, airborne dust can enter surrounding buildings, and excess water can collect in nearby yards and basements.

**Safety considerations.** Possible health dangers of each method selected for the cleaning project must be considered before selecting a cleaning method to avoid harm to the

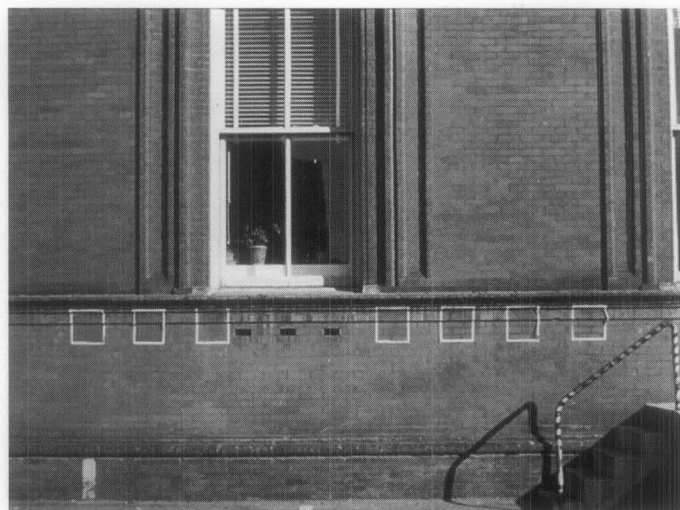


Figure 22. Cleaning test areas may be quite small at first and gradually increase in size as testing determines the "gentlest means possible".  
Photo: Frances Gale.

cleaning applicators, and the necessary precautions must be taken. The precautions listed in Material Safety Data Sheets (MSDS) that are provided with chemical products should always be followed. Protective clothing, respirators, hearing and face shields, and gloves must be provided to workers to be worn at all times. Acidic and alkaline chemical cleaners in both liquid and vapor forms can also cause serious injury to passers-by (Fig. 23). It may be necessary to schedule cleaning at night or weekends if the building is located in a busy urban area to reduce the potential danger of chemical overspray to pedestrians. Cleaning during non-business hours will allow HVAC systems to be turned off and vents to be covered to prevent dangerous chemical fumes from entering the building which will also ensure the safety of the building's occupants. Abrasive and mechanical methods produce dust which can pose a serious health hazard, particularly if the abrasive or the masonry contains silica.

## Water-Repellent Coatings and Waterproof Coatings

To begin with, it is important to understand that waterproof coatings and water-repellent coatings are not the same. Although these terms are frequently interchanged and commonly confused with one another, they are completely different materials. **Water-repellent coatings** – often referred to incorrectly as "sealers", but which do not or should not seal – are intended to keep liquid water from penetrating the surface but to allow water vapor to enter and leave, or pass through, the surface of the masonry (Fig. 24). Water-repellent coatings are generally *transparent*, or clear, although once applied some may darken or discolor certain types of masonry while others may give it a glossy or shiny appearance. **Waterproof coatings** seal the surface from liquid water and from water vapor. They are usually *opaque*, or pigmented, and include bituminous coatings and some elastomeric paints and coatings.

## Water-Repellent Coatings

Water-repellent coatings are formulated to be vapor permeable, or "breathable". They do not seal the surface completely to water vapor so it can enter the masonry wall as well as leave the wall. While the first water-repellent coatings to be developed were primarily acrylic or silicone resins in organic solvents, now most water-repellent coatings are water-based and formulated from modified siloxanes, silanes and other alkoxysilanes, or metallic stearates. While some of these products are shipped from the factory ready to use, other waterborne water repellents must be diluted at the job site. Unlike earlier water-repellent coatings which tended to form a "film" on the masonry surface, modern water-repellent coatings actually penetrate into the masonry substrate slightly and, generally, are almost invisible if properly applied to the masonry. They are also more vapor permeable than the old coatings, yet they still reduce the vapor permeability of the masonry. Once inside the wall, water vapor can condense at cold spots producing liquid water which, unlike water vapor, cannot escape through a water-repellent coating. The liquid water within the wall, whether from condensation, leaking gutters, or other sources, can cause considerable damage.

Water-repellent coatings are not consolidants. Although modern water repellents may penetrate slightly beneath the masonry surface, instead of just "sitting" on top of it, they do not perform the same function as a consolidant which is to "consolidate" and replace lost binder to strengthen deteriorating masonry. Even after many years of laboratory study and testing few consolidants have proven very effective. The composition of fired products such as brick and architectural terra cotta, as well as many types of building stone, does not lend itself to consolidation.

Some modern water-repellent coatings which contain a binder intended to replace the natural binders in stone that have been lost through weathering and natural erosion are described in product literature as both a water repellent and a consolidant. The fact that newer water-repellent coatings penetrate beneath the masonry surface instead of just forming a layer on top of the surface may indeed convey at least some consolidating properties to certain stones. However, a water-repellent coating cannot be considered a consolidant. In some instances, a water-repellent or "preservative" coating, if applied to already damaged or spalling stone, may form a surface crust which, if it fails, may exacerbate the deterioration by pulling off even more of the stone (Fig. 25).

### Is a Water-Repellent Treatment Necessary?

Water-repellent coatings are frequently applied to historic masonry buildings for the wrong reason. They also are often applied without an understanding of what they are and what they are intended to do. And these coatings can be very difficult, if not impossible, to remove from the masonry if they fail or become discolored. Most importantly, the application of water-repellent coatings to historic masonry is usually unnecessary.



Figure 23. A tarpaulin protects and shields pedestrians from potentially harmful spray while chemical cleaning is underway on the granite exterior of the U.S. Treasury Building, Washington, D.C.

Most historic masonry buildings, unless they are painted, have survived for decades without a water-repellent coating and, thus, probably do not need one now. Water penetration to the interior of a masonry building is seldom due to porous masonry, but results from poor or deferred maintenance. Leaking roofs, clogged or deteriorated gutters and downspouts, missing mortar, or cracks and open joints around door and window openings are almost always the cause of moisture-related problems in a historic masonry building. **If historic masonry buildings are kept watertight and in good repair, water-repellent coatings should not be necessary.**

Rising damp (capillary moisture pulled up from the ground), or condensation can also be a source of excess moisture in masonry buildings. A water-repellent coating will not solve this problem either and, in fact, may be likely to exacerbate it. Furthermore, a water-repellent coating should never be applied to a damp wall. Moisture in the wall would reduce the ability of a coating to adhere to the masonry and to penetrate below the surface. But, if it did adhere, it would hold the moisture inside the masonry because, although a water-repellent coating is permeable to water vapor, liquid water cannot pass through it. In the case of rising damp, a coating may force the moisture to go even higher in the wall because it can slow down evaporation, and thereby retain the moisture in the wall.

Excessive moisture in masonry walls may carry waterborne soluble salts from the masonry units themselves or from the mortar through the walls. If the water is permitted to come to the surface, the salts may appear on the masonry surface as efflorescence (a whitish powder) upon evaporation. However, the salts can be potentially dangerous if they remain in the masonry and crystallize



Figure 24. Although the application of a water-repellent coating was probably not needed on either of these buildings, the coating on the brick building (above), is not visible and has not changed the character of the brick. But the coating on the brick column (below), has a high gloss that is incompatible with the historic character of the masonry.



beneath the surface as subflorescence. Subflorescence eventually may cause the surface of the masonry to spall, particularly if a water-repellent coating has been applied which tends to reduce the flow of moisture out from the subsurface of the masonry. Although many of the newer water-repellent products are more breathable than their predecessors, they can be especially damaging if applied to masonry that contains salts, because they limit the flow of moisture through masonry.

### When a Water-Repellent Coating May be Appropriate

There are some instances when a water-repellent coating may be considered appropriate to use on a historic masonry building. Soft, incompletely fired brick from the 18th- and early-19th centuries may have become so porous that paint or some type of coating is needed to protect it from further deterioration or dissolution. When a masonry building has been neglected for a long period of time, necessary repairs may be required in order to make it watertight. If, following a reasonable period of time after the building has been made watertight and has dried out completely, moisture appears actually to be penetrating through the repointed and repaired masonry walls, then the application of a water-repellent coating may be considered *in selected areas only*. This decision should be made in consultation with an architectural conservator. And, if such a treatment is undertaken, it should not be applied to the entire exterior of the building.

Anti-graffiti or barrier coatings are another type of clear coating—although barrier coatings can also be pigmented—that may be applied to exterior masonry, but they are not formulated primarily as water repellents. The purpose of these coatings is to make it harder for graffiti to stick to a masonry surface and, thus, easier to clean. But, like water-repellent coatings, in most cases the application of anti-graffiti coatings is generally not recommended for historic masonry buildings. These coatings are often quite shiny which can greatly alter the appearance of a historic masonry surface, and they are not always effective (Fig. 26). Generally, other ways of discouraging graffiti, such as improved lighting, can be more effective than a coating. However, the application of anti-graffiti coatings may be appropriate in some instances on vulnerable areas of historic masonry buildings which are frequent targets of graffiti that are located in out-of-the-way places where constant surveillance is not possible.

Some water-repellent coatings are recommended by product manufacturers as a means of keeping dirt and pollutants or biological growth from collecting on the surface of masonry buildings and, thus, reducing the need for frequent cleaning. While this at times may be true, in some cases a coating may actually retain dirt more than uncoated masonry. Generally, the application of a water-repellent coating is not recommended on a historic masonry building as a means of preventing biological growth. Some water-repellent coatings may actually encourage biological growth on a masonry wall. Biological growth on masonry buildings has traditionally been kept at bay through regularly-scheduled cleaning as part of a maintenance plan. Simple cleaning of the masonry with low-pressure water using a natural- or synthetic-bristled scrub brush can be very effective if done on a regular basis. Commercial products are also available which can be sprayed on masonry to remove biological growth.

**In most instances, a water-repellent coating is not necessary if a building is watertight.** The application of a water-repellent coating is not a recommended treatment for historic masonry buildings unless there is a specific



Figure 25. The clear coating applied to this limestone molding has failed and is taking off some of the stone surface as it peels. Photo: Frances Gale.

problem which it may help solve. If the problem occurs on only part of the building, it is best to treat only that area rather than an entire building. Extreme exposures such as parapets, for example, or portions of the building subject to driving rain can be treated more effectively and less expensively than the entire building. Water-repellent coatings are not permanent and must be reapplied

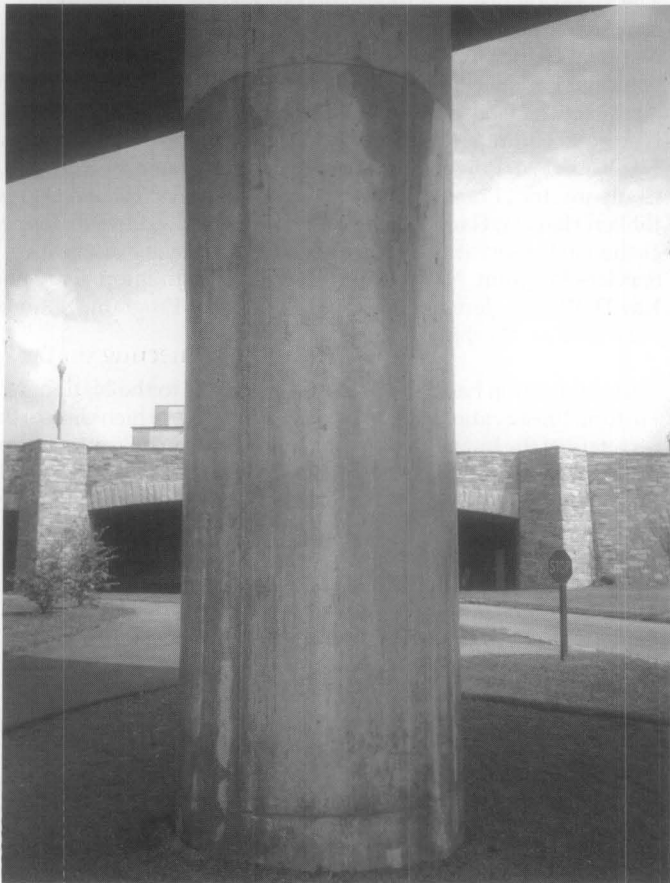


Figure 26. The anti-graffiti or barrier coating on this column is very shiny and would not be appropriate to use on a historic masonry building. The coating has discolored as it has aged and whitish streaks reveal areas of bare concrete where the coating was incompletely applied.

periodically although, if they are truly invisible, it can be difficult to know when they are no longer providing the intended protection.

Testing a water-repellent coating by applying it in one small area may not be helpful in determining its suitability for the building because a limited test area does not allow an adequate evaluation of such a treatment. Since water may enter and leave through the surrounding untreated areas, there is no way to tell if the coated test area is "breathable." But trying a coating in a small area may help to determine whether the coating is visible on the surface or if it will otherwise change the appearance of the masonry.

### Waterproof Coatings

In theory, waterproof coatings usually do not cause problems as long as they exclude all water from the masonry. If water does enter the wall from the ground or from the inside of a building, the coating can intensify the damage because the water will not be able to escape. During cold weather this water in the wall can freeze causing serious mechanical disruption, such as spalling.

In addition, the water eventually will get out by the path of least resistance. If this path is toward the interior, damage to interior finishes can result; if it is toward the exterior, it can lead to damage to the masonry caused by built-up water pressure (Fig. 27).

**In most instances, waterproof coatings should not be applied to historic masonry.** The possible exception to this might be the application of a waterproof coating to below-grade exterior foundation walls as a last resort to stop water infiltration on interior basement walls. **Generally, however, waterproof coatings, which include elastomeric paints, should almost never be applied above grade to historic masonry buildings.**



Figure 27. Instead of correcting the roof drainage problems, an elastomeric coating was applied to the already saturated limestone cornice. An elastomeric coating holds moisture in the masonry because it does not "breathe" and does not allow liquid moisture to escape. If the water pressure builds up sufficiently it can cause the coating to break and pop off as shown in this example, often pulling pieces of the masonry with it. Photo: National Park Service Files.

## Summary

A well-planned cleaning project is an essential step in preserving, rehabilitating or restoring a historic masonry building. Proper cleaning methods and coating treatments, when determined necessary for the preservation of the masonry, can enhance the aesthetic character as well as the structural stability of a historic building. Removing years of accumulated dirt, pollutant crusts, stains, graffiti or paint, if done with appropriate caution, can extend the life and longevity of the historic resource. Cleaning that is carelessly or insensitively prescribed or carried out by inexperienced workers can have the opposite of the intended effect. It may scar the masonry permanently, and may actually result in hastening deterioration by introducing harmful residual chemicals and salts into the masonry or causing surface loss. Using the wrong cleaning method or using the right method incorrectly, applying the wrong kind of coating or applying a coating that is not needed can result in serious damage, both physically and aesthetically, to a historic masonry building. Cleaning a historic masonry building should always be done using the *gentlest means possible* that will clean, but not damage the building. It should always be taken into consideration before applying a water-repellent coating or a waterproof coating to a historic masonry building whether it is really necessary and whether it is in the best interest of preserving the building.

## Selected Reading

*Architectural Ceramics: Their History, Manufacture and Conservation*. A Joint Symposium of English Heritage and the United Kingdom Institute for Conservation, September 22-25, 1994. London: English Heritage, 1996.

Ashurst, Nicola. *Cleaning Historic Buildings. Volume One: Substrates, Soiling & Investigation. Volume Two: Cleaning Materials & Processes*. London: Donhead Publishing Ltd., 1994.

Association for Preservation Technology. *Special Issue: Preservation of Historic Masonry*. Papers from the Symposium on Preservation Treatments for Historic Masonry: Consolidants, Coatings, and Water Repellents, New York, New York, November 11-12, 1994. *APT Bulletin*. Vol. XXVI, No. 4 (1995).

Grimmer, Anne E. *Preservation Brief 6: Dangers of Abrasive Cleaning to Historic Buildings*. Washington, D.C.: Preservation Assistance Division, National Park Service, U.S. Department of the Interior, 1979.

Grimmer, Anne E. *Keeping it Clean: Removing Exterior Dirt, Paint, Stains and Graffiti from Historic Masonry Buildings*. Washington, D.C.: Preservation Assistance Division, National Park Service, U.S. Department of the Interior, 1988.

Park, Sharon C., AIA. *Preservation Brief 39: Holding the Line: Controlling Unwanted Moisture in Historic Buildings*. Washington, D.C.: Heritage Preservation Services, National Park Service, U.S. Department of the Interior, 1996.

Powers, Robert M. *Preservation Tech Note, Masonry No. 3, "Water Soak Cleaning of Limestone"*. Washington, D.C.: Preservation Assistance Division, National Park Service, U.S. Department of the Interior, 1992.

Sinvinski, Valerie. "Gentle Blasting." *Old-House Journal*. Vol. XXIV, No. 4 (July-August 1996), pp. 46-49.

Weaver, Martin E. *Conserving Buildings: A Guide to Techniques and Materials*. New York: John Wiley & Sons, Inc., 1993.

Weaver, Martin E. *Preservation Brief 38: Removing Graffiti from Historic Masonry*. Washington, D.C.: Preservation Assistance Division, National Park Service, U.S. Department of the Interior, 1995.

Winkler, E.M. *Stone in Architecture: Properties, Durability*. Third, completely revised and extended edition. Berlin, Germany: Springer-Verlag, 1997.

## Acknowledgments

**Robert C. Mack, FAIA**, is a principal in the firm of MacDonald & Mack Architects, Ltd., an architectural firm that specializes in historic buildings in Minneapolis, Minnesota.

**Anne Grimmer** is a Senior Architectural Historian in the Technical Preservation Services Branch, Heritage Preservation Services Program, National Park Service, Washington, D.C.

The original version of *Preservation Brief 1: The Cleaning and Waterproof Coating of Masonry Buildings* was written by Robert C. Mack, AIA. It inaugurated the *Preservation Briefs* series when it was published in 1975.

The following historic preservation specialists provided technical review of this publication: Frances Gale, Training Director, National Center for Preservation Technology and Training, National Park Service, Natchitoches, LA; Judith M. Jacob, Architectural Conservator, Building Conservation Branch, Northeast Cultural Resources Center, National Park Service, N.Y., NY; Robert M. Powers, Architectural Conservator, Powers and Company, Inc., Philadelphia, PA; Antonio Aguilar, Kaaren Dodge, JoEllen Hensley, Gary Sachau, John Sandor and Audrey T. Tepper, Technical Preservation Services Branch, Heritage Preservation Services Program, National Park Service, Washington, D.C.; and Kay D. Weeks, Heritage Preservation Services Program, National Park Service, Washington, D.C.

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. Comments on the usefulness of this publication may be directed to: Sharon C. Park, FAIA, Chief, Technical Preservation Services Branch, Heritage Preservation Services Program, National Park Service, 1849 C Street, N.W., Suite NC200, Washington, D.C. 20240 ([www2.cr.nps.gov/tps](http://www2.cr.nps.gov/tps)). This publication is not copyrighted and can be reproduced without penalty. Normal procedures for credit to the authors and the National Park Service are appreciated.

*Front Cover: Chemical cleaning of the brick and architectural terra cotta frieze on the 1880s Pension Building, Washington, D.C. (now the National Building Museum), is shown here in progress. Photo: Christina Henry.*

*Photographs used to illustrate this Brief were taken by Anne Grimmer unless otherwise credited.*



# 3 PRESERVATION BRIEFS

## Improving Energy Efficiency in Historic Buildings

Jo Ellen Hensley and Antonio Aguilar



National Park Service  
U.S. Department of the Interior

Technical Preservation Services



The concept of energy conservation in buildings is not new. Throughout history building owners have dealt with changing fuel supplies and the need for efficient use of these fuels. Gone are the days of the cheap and abundant energy of the 1950's. Today with energy resources being depleted and the concern over the effect of greenhouse gases on climate change, owners of historic buildings are seeking ways to make their buildings more energy efficient. These concerns are key components of sustainability — a term that generally refers to the ability to maintain the environmental, social, and economic needs for human existence. The topic of sustainable or “green” building practices is too broad to cover in this brief. Rather, this preservation brief is intended to help property owners, preservation professionals, and stewards of historic buildings make informed decisions when considering energy efficiency improvements to historic buildings.

Sound energy improvement measures must take into consideration not only potential energy savings, but also the protection of the historic property's materials and features. This guidance is provided in accordance with the Secretary of the Interior's Standards for Rehabilitation to ensure that the architectural integrity of the historic property is preserved. Achieving a successful retrofit project must balance the goals of energy efficiency with the least impact to the historic building. Planning must entail a holistic approach that considers the entire building envelope, its systems and components, its site and environment, and a careful evaluation of the effects of the measures undertaken. Treatments common to new construction need to be evaluated carefully before implementing them in historic buildings in order to avoid inappropriate alteration of important architectural features and irreparable damage to historic building materials. This brief targets primarily small-to medium-size historic buildings, both residential and commercial. However, the general decision-making principles outlined here apply to buildings of any size and complexity.

### Inherent Energy Efficient Features of Historic Buildings

Before implementing any energy conservation measures, the existing energy-efficient characteristics of a historic building should be assessed. Buildings are more than the sum of their individual components. The design, materials, type of construction, size, shape, site orientation, surrounding landscape, and climate all play a role in how buildings perform. Historic building construction methods and materials often maximized natural sources of heat, light and ventilation to respond to local climatic conditions. The key to a successful rehabilitation project is to understand and identify the existing energy-efficient aspects of the historic building and how they function, as well as to understand and identify its character-defining features to ensure they are preserved. Whether rehabilitated for a new or continuing use, it is important to utilize the historic building's inherent sustainable qualities as they were intended to ensure that they function effectively together with any new treatments added to further improve energy efficiency.

#### Windows, courtyards, and light wells

Operable windows, interior courtyards, clerestories, skylights, rooftop ventilators, cupolas, and other features that provide natural ventilation and light can reduce energy consumption. Whenever these devices can be used to provide natural ventilation and light, they save energy by reducing the need to use mechanical systems and interior artificial lighting.

Historically, builders dealt with the potential heat loss and gain from windows in a variety of ways depending on the climate. In cold climates where winter heat loss from buildings was the primary consideration before mechanical systems were introduced, windows were limited to those necessary for adequate light and ventilation. In historic buildings where the ratio of glass



Fig. 1. A decorative, stained glass skylight allows natural daylight into the interior.

to wall is less than 20%, the potential heat loss through the windows is likely minimal; consequently, they are more energy efficient than most recent construction. In hot climates, numerous windows provided valuable ventilation, while features such as wide roof overhangs, awnings, interior or exterior shutters, venetian blinds, shades, curtains and drapes significantly reduced heat gain through the windows. Historic windows can play an important role in the efficient operation of a building and should be retained.



Fig. 2. Upper and lower shutters control daylight and provide privacy.

New architectural styles, beginning with the International Style of the 1920's, brought about an increase in the percentage of glazing in the total building envelope. By the 1950's, with the advent of the glass curtain wall, glazing constituted nearly 100% of a building's exterior walls in many buildings. While many early modern buildings continued to use operable windows as a way to provide natural ventilation, greater reliance on mechanical heating and air conditioning systems eventually reduced the function of exterior glazing to providing light only, particularly in commercial, office, and institutional buildings.



Fig. 3. Stone walls with substantial mass have high thermal inertia.

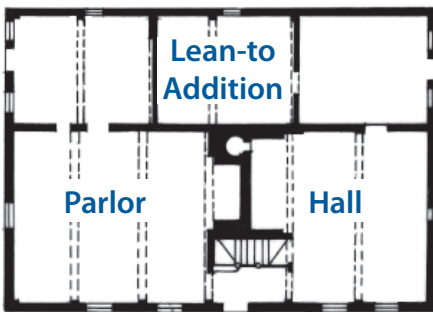
### Walls

Thick masonry walls typical of the late-nineteenth and early-twentieth centuries have inherent thermal characteristics that keep the buildings cooler in the summer and warmer in the winter. Walls with substantial mass have the advantage of high thermal inertia, which reduces the rate of heat transfer through the wall. For instance, a wall with high thermal inertia, subjected to solar radiation for an hour, will absorb the heat at its outside surface, but slowly transfer it to the interior over a period as long as six hours. Conversely, a wall having the equivalent thermal resistance (R-value), but a substantially lower thermal inertia, will transfer the heat in perhaps as little as two hours. Heavy masonry walls also reduce the need for summer cooling. High thermal inertia is the reason many older public and commercial buildings without air conditioning still feel cool during the summer. The heat from the midday sun does not penetrate the buildings until late afternoon and evening, when it is less likely to be occupied or when exterior temperatures have fallen. Heavy masonry walls are also effective in moderating internal temperatures in the winter by dampening the overall peaks of heat gain and loss resulting in a flatter and more tolerable daily cycle. In areas that require cooling during the day and heating at night, masonry walls can help spread out excess heat gain from the day to cover some of the needed heating for the evening and night hours.

### Roofs

Roof construction and design in historic buildings, particularly vernacular buildings, are strongly

influenced by the conditions of the local climate. Wide overhangs that sometimes extend to create porches minimize the heat gain from the sun in warmer climates, while steep, sloping roofs with minimal or no overhang prevail in colder climates to allow for shedding snow and increasing beneficial solar heat gain through the windows. Materials and color also influence the thermal performance of roofs. Metal and light colored roofs, for example, reflect sunlight and thereby reduce the heat gain from solar radiation.



*Fig. 4. A typical New England saltbox features a steeply sloping roof to shed snow and a floor plan organized around a central chimney to conserve heat.*

### Floor Plans

The floor plan of many historic buildings, particularly traditional vernacular ones, was also designed to respond to the local climate. In cold climates, rooms with low ceilings were clustered around central chimneys to share the heat, while small windows with interior shutters reduced drafts and heat loss. In warmer climates, wide central halls with tall ceilings, breezeways, and large porches all maximized air circulation.

### Landscape

Site orientation was another factor considered especially in the location of a historic building on its property. In cold climates, buildings were oriented against northern winds while buildings in warm climates were sited to take advantage of prevailing breezes. Evergreen trees planted on the north side of buildings shielded from winter winds; deciduous trees planted to the south provided summer shade and maximum sun in the winter.



*Fig. 5. The side porches of this house in Charleston, SC, shade the large windows and provide outdoor living spaces that take advantage of sea breezes.*

## Energy Audit

Before implementing any measures to improve the thermal performance of a historic building, an energy audit should be undertaken to evaluate the current energy use of the building and identify deficiencies in the building envelope or mechanical systems. In some areas, the local utility company may offer a free simple audit, however a more in-depth audit should be obtained from a professional energy auditor. The goal of the audit is to establish a baseline of building performance data to serve as a reference point when evaluating the effectiveness of future energy improvements. It is important to hire an independent auditor who does not have financial interests in the results, such as a product vendor.

An energy auditor first documents the current energy use patterns in the building to establish an energy use history. This initial step includes obtaining the billing history from the local utility company over a one- or two-year period, as well as documenting the number of building occupants, how the building is used, and the type of fuel consumed. The location of any existing insulation is recorded and the approximate R-value of various components of the building envelope including walls, ceilings, floors, doors, windows and skylights is calculated. The building envelope is inspected to identify areas of air infiltration and air loss. The type and age of mechanical systems and major appliances are also recorded.

Tools such as a blower door test or infrared thermography are useful to identify specific areas of infiltration, lack of insulation and thermal bridging. Mechanical depressurization along with infrared thermography is extremely useful in identifying locations of air leakage and heat loss followed by the use of tracer smoke to isolate specific air leaks. These tests are often challenging to perform on buildings and must be undertaken by experienced professionals to avoid

misleading or inaccurate results. There are professional standards for audits, those of the Building Performance Institute (BPI) being the most widely used.

The energy auditor then produces a detailed report that documents the findings of the audit and includes specific recommendations for upgrades such as air sealing, adding insulation, general repairs, lighting, and improvements to or replacement of mechanical systems or major appliances. Cost estimates are provided for each of the improvements including the cost of implementation, potential operating cost savings, and, importantly, the anticipated payback period. Armed with this information, historic building owners can start to make informed decisions on how to improve the performance of their buildings. Usually the auditor finds a few locations where there is major air leakage; large “holes” that are unique to a particular building and require equipment to find them. These anomalies are often invisible to the people who use the building on a regular basis. It is important to retest the performance of the building following the implementation of any upgrades undertaken as a result of an energy audit to ensure that the upgrades are performing as expected.

### Prioritizing Energy Upgrades

When implementing energy upgrades, efforts should be concentrated on improvements that will provide the most payback for the money expended and the least compromise to the historic character of the building. Some upgrades recommended in energy audits may not be introduced into a historic building feasibly without damaging historic fabric or altering the appearance of significant features. Removing historic siding and replacing it with new siding to introduce insulation

into the wall cavity of a frame building or replacing repairable historic windows are examples of treatments that should not be undertaken on historic buildings.

A common misconception is that replacing windows alone will result in major energy savings. This argument, often used to sell replacement windows, is simply not true. Although it varies from building to building, the U.S. Department of Energy (DOE) has documented that air loss attributable to windows in most buildings is only about 10% of the total air loss. Studies have shown that window replacement does not pay for itself in energy savings in a reasonable length of time. Moreover, there are ways to improve the performance of historic windows that do not require their replacement. In addition, historic windows can usually be repaired and are, thus, sustainable, while most new windows cannot be repaired, or even recycled, and may wind up in landfills.

When considering energy upgrades, it is imperative to get a clear picture of what an improvement will cost initially and how long it will take to pay back the cost in energy savings. Therefore, the life cycle cost of the improvement must be considered as well as its impact on historic fabric. Reducing infiltration around existing windows and doors, sealing penetrations in the building envelope, and adding insulation — particularly in the attic where it has little impact on historic fabric — can result in significant improvements at relatively little cost. Updating mechanical systems or changing the way in which they are operated can also be cost-effective interventions. For example, installing a more efficient mechanical system alone may pay for itself in ten years.



Fig. 6. (left) A blower door is used to depressurize a building by exhausting air at a rate that allows pressure gages and tracer smoke to measure the amount and location of air leakage. Photo: Robert Cagnetta, Heritage Restoration, Inc.



Fig. 7. (center and right) The left thermal image shows the walls of this building before insulating. After insulation was added, the cooler and, thus darker exterior walls evidence how much the heat loss has been reduced. Photos: EYP Architecture & Engineering.

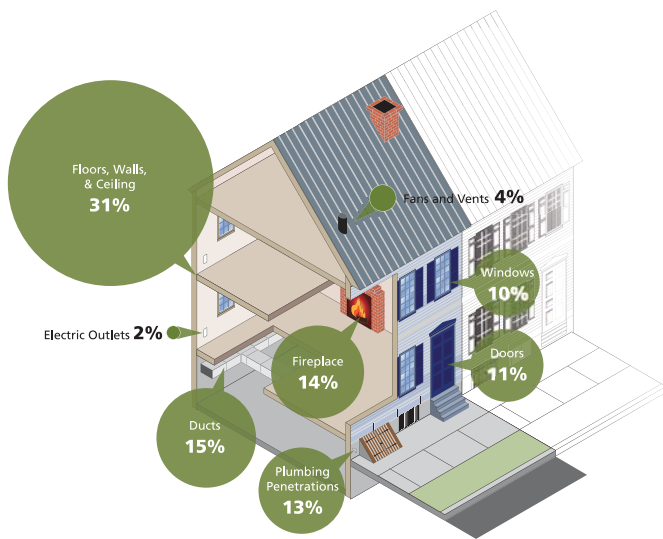


Fig. 8. Where Air Escapes From a House (by percentage) – Image based on data from Energy Savers, U.S. Department of Energy. Illustration: Blank Space LLC.

## Actions to Improve Energy Efficiency

Reducing energy demands for heating and cooling may be accomplished in two steps. First, implement operational changes and upgrades to mechanical systems and major appliances — measures that do not require making alterations or adding new materials — to ensure that a building functions as efficiently as possible. After all these measures have been implemented, corrective work or treatments, such as weatherization, that require other alterations to the building may be considered.

### Residential Energy Use Intensity by Age

Year Built	KBtu/sq ft/yr
Prior to 1950	74.5
1950 to 1969	66.0
1970 to 1979	59.4
1980 to 1989	51.9
1990 to 1999	48.2
2000 to 2005	44.7

Source: Residential Energy Consumption Survey, 2005

### Establishing Realistic Goals

Energy consumption data gathered by the U.S. Energy Information Administration (see chart) shows that residential buildings built before 1950 (the largest percentage of historic building stock) are about 30 to 40 percent less energy efficient than buildings built after 2000. Using this as a baseline, a 30 to 40 percent upgrade of a historic building’s energy performance can be a realistic goal. A 40 percent increase in energy efficiency would of course be a more achievable goal for buildings that have had minimal upgrades since their

original construction, i.e., added insulation, tightening of the exterior envelope, or more efficient mechanical equipment. On the other hand, achieving “net zero” energy goals as it is currently done with some new construction can be a much more difficult challenge to achieve in a historic retrofit. Attempting to reach such a goal with a historic building would most likely result in significant alterations and loss of historic materials. [The data for commercial buildings documents that buildings in 2003 used approximately the same energy as they did before 1920, after reaching their peak in the 1980’s.]

### Operational Changes

One of the greatest effects on energy use is user behavior. Once an energy audit has established a baseline for the current energy use in a building, operational changes should be identified to control how and when the building is used to minimize the use of energy-consuming equipment. These changes can range from simple measures such as regular cleaning and maintenance of mechanical equipment to installing sophisticated controls that cycle equipment on and off in specified intervals for maximum performance. The following changes are recommended to reduce heating and cooling costs.

- Install programmable thermostats.
- Close off rooms that are not in use and adjust the temperature in those rooms.
- Do not condition rooms that do not need to be conditioned, thereby reducing the thermal envelope.
- Use insulated shades and curtains to control heat gain and loss through windows.
- Use operable windows, shutters, awnings and vents as originally intended to control temperature and ventilation.
- Take advantage of natural light.
- Install compact fluorescent lights (CFL) and light-emitting diode (LED) lights.
- Install motion sensors and timers for lighting and local ventilation, such as bathroom exhaust fans.
- Reduce “phantom” electricity loads by turning equipment off when not in use.
- Clean and service mechanical equipment regularly.

These measures should be undertaken first to save energy in any existing building and are particularly appropriate for historic buildings because they do not require alterations to historic materials.

### Upgrading Equipment and Appliances

In addition to maximizing the energy efficiency of existing building systems, substantial savings can be achieved through upgrading equipment and appliances. One should still weigh the operational savings against the initial cost of the new equipment, particularly if the existing equipment is not near the end of its life.

Calculator aids that take into account the efficiency of both the existing and new equipment are available



Fig. 9. An energy auditor tests the efficiency of a boiler.

online to assist in determining the payback. Advance planning will allow time to find the most efficient unit, as well as to investigate the availability of any state and federal energy credits. As energy prices continue to rise and technology advances, options such as the installation of a solar hot water heater or geothermal ground source or water source heat pumps are becoming more economically feasible. Recommendations for upgrading equipment and appliances include:

- Upgrade the heating system. It is important to install new furnaces that utilize outside combustion air to reduce air drawn into the building through uncontrolled infiltration. [All furnaces and boilers are now measured by their annual fuel utilization efficiency or AFUE.] Heating equipment is now more efficient and gas furnaces that used to have a 60% (AFUE) rating can now operate at as much as 90 to 97% efficiency.
- Upgrade the air conditioning system.
- Replace the water heater. High-efficiency water heaters use far less energy than earlier models, and high-efficiency tankless water heaters heat water on demand and offer even greater savings. Point of use water heat can also reduce costs and water consumption by reducing the time it takes to draw hot water.
- Upgrade appliances. Energy Star appliances, particularly refrigerators, washing machines and dishwashers can all reduce electricity use and additional indoor heating loads.

### Upgrading Building Components

In addition to operational and mechanical upgrades, it can be possible to upgrade many building components in a manner that will not jeopardize the historic character of the building and can be accomplished at a reasonable cost. The goal of these upgrades is to improve the thermal performance of the building, resulting in even greater energy savings. Retrofit measures to historic buildings should be limited to those that achieve at least reasonable energy savings, at reasonable costs, with the least impact on the character of the building.

The following list includes the most common measures proposed to improve the thermal performance of an existing building; some measures are highly recommended for historic buildings, but others are less beneficial, and can even be harmful to a historic building.

#### Requires Minimal Alteration

- Reduce air leakage.
- Add attic insulation.
- Install storm windows.
- Insulate basements and crawlspaces.
- Seal and insulate ducts and pipes.
- Weather strip doors and add storm doors.
- Add awnings and shading devices where appropriate.

#### Requires More Alteration

- Add interior vestibules.
- Replace windows.
- Add insulation to wood-frame walls.
- Add insulation to masonry walls.
- Install cool roofs and green roofs.

The treatments listed first have less potential to negatively impact the historic fabric of a building. They tend to be less intrusive, are often reversible, and offer the highest potential for energy savings. Undertaking any of the treatments in the second group, however, may pose technical problems and damage to historic building materials and architectural features. Their installation costs may also outweigh the anticipated energy savings and must be evaluated on a case-by-case basis with advice from professionals experienced in historic preservation and building performance.

#### Requires Minimal Alteration

**Reduce air leakage.** Reducing air leakage (infiltration and exfiltration) should be the first priority of a preservation retrofit plan. Leakage of air into a building can account for 5 to 40 percent of space-conditioning costs, which can be one of the largest operational costs for buildings.<sup>1</sup> In addition, unwanted air leakage into and out of the building can lead to occupant comfort issues resulting from drafts. Air infiltration can be especially problematic in historic buildings because it is closely linked to increased moisture movement into building systems.

Air flow into and out of buildings is driven by three primary forces: wind pressure, mechanical pressure and the stack effect. Cold outside air that infiltrates the building through big holes, as well as through loose windows, doors, and cracks in the outer shell of the building, causes the heating system to work harder and consume more energy. In a multi-story building, cold air that enters the building at lower levels, including the basement or crawlspace, will travel up through the building and exit out leaky windows, gaps around windows and the attic as a result of temperature and pressure differential. This pattern of air movement

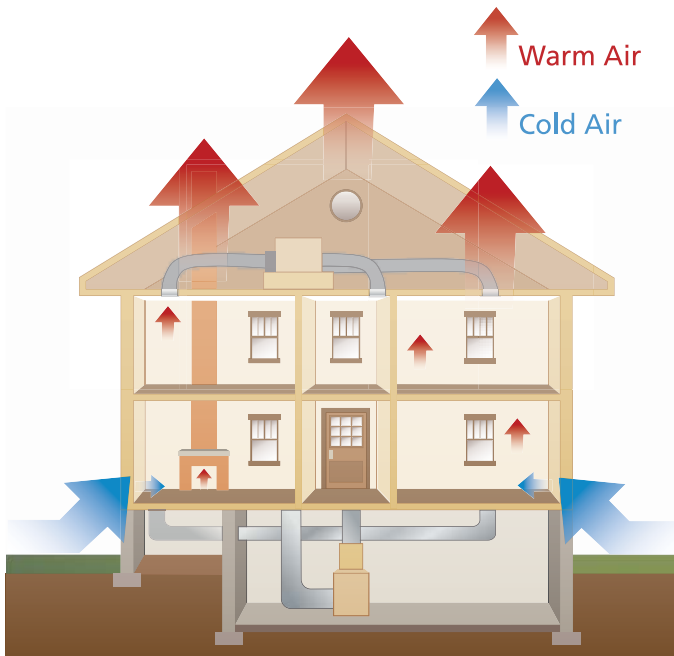


Fig. 10. The pattern of air movement referred to as the "stack effect".  
Illustration: Blank Space LLC.

is called the "stack effect." Not only is valuable conditioned air lost, but damaging moisture may also enter the wall cavities and attic spaces. To stop the stack effect, the top and bottom of the exterior walls, inter-floor bypasses, and any existing chases or shafts must be sealed, or "draft proofed." The use of spray foam sealants in basement and attic cracks is a particularly useful technique for reducing air infiltration.

Adding weatherstripping to doors and windows, sealing open cracks and joints at the base of walls and around windows and doors, sealing off recessed lighting fixtures from above, and sealing the intersection of walls and attic, will substantially reduce air leakage. When using exterior caulk to seal the intersection of siding and doors or windows, do not caulk the underside of clapboards or below windows to allow any liquid water to escape. When infiltration and, consequently, exfiltration are reduced, mechanical ventilation may be necessary to meet occupants' requirements for fresh air.

**Add attic or roof insulation.** Heat loss and gain caused by increased interior/ exterior temperature differentials primarily due to the stack effect and solar radiation are greatest at the top of a building. Therefore, reducing heat transfer through the roof or attic should be one of the highest priorities in reducing energy consumption. Adding insulation in unoccupied, unfinished attics is not only very effective from an energy-savings perspective, but it is also generally simple to install and causes minimal disruption to historic materials. The U.S. Department of Energy (DOE) provides a recommended R-value chart based on climate zones to help determine the optimal amount of insulation that should be installed in a particular project. Local codes may also have specific insulation requirements. Insulating trap or access doors should not be overlooked. Even though they may be

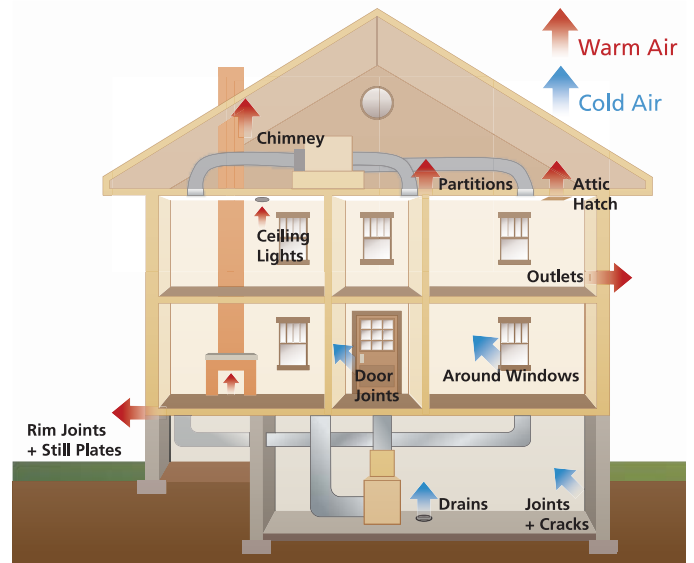


Fig. 11. Air infiltration and exfiltration.  
Illustration: Blank Space LLC.

small, attic doors can be responsible for substantial heat loss and should be addressed as part of any attic insulation project.

### DOE Climate Zone Map

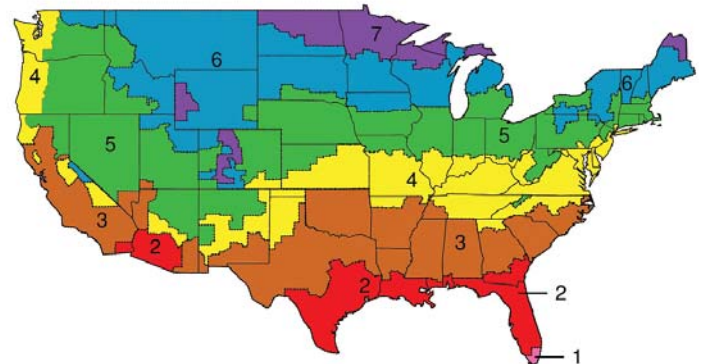


Fig. 12. Recommended energy improvements vary widely based on climate. The information contained in this document is based primarily on the available data for the Northeast and Mid-Atlantic regions.

In unfinished and unheated attics, the insulation material is typically placed between the floor joists using blown-in, batt, or rigid foam insulation. When using fiberglass batts faced with a vapor retarder, the vapor retarder should be face down towards the heated interior. However, the use of a vapor retarder is not necessary in attic applications. If additional batt insulation is being added over existing insulation that is near or above the top of the joists, new un-faced batts should be placed perpendicular to the old ones to cover the top of the joists and reduce thermal bridging through the frame members. In low-pitched roofs, or where installing batt insulation is difficult, a more complete coverage of the attic floor may be achieved by using blown-in insulation. Unfinished attics must be properly ventilated to allow excess heat to escape.

Radiant barriers may be used in attics to reduce thermal radiation across the air space between the roof deck and the attic floor in order to reduce summer heat gain. They are most beneficial in reducing cooling loads in hot climates and consist of a highly reflective sheet or coating, usually aluminum, applied to one or both sides of a flexible material. They are effective only when the foil surface faces an air space, and as long as the surface remains shiny – that is, free from dirt, dust, condensation and oxidation. Radiant barriers should not be installed directly over insulation on the attic floor, as they can act as vapor retarders and trap moisture in the insulation unless they are perforated. Their placement should be ventilated on both sides.

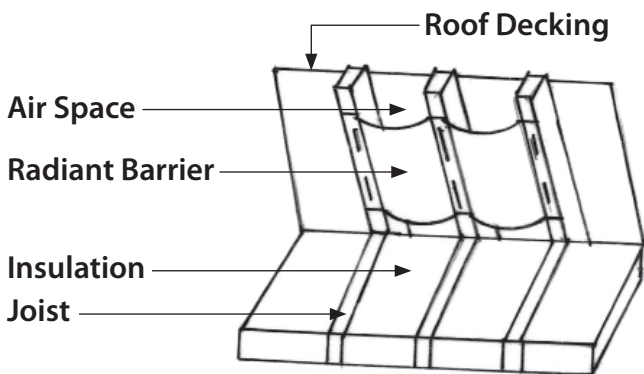


Fig. 13. Sample installation of a radiant barrier.

Insulating the underside of the roof rather than the attic floor increases the volume of the thermal envelope of the building, thus making this treatment inherently less energy efficient. However, when mechanical equipment and/or ductwork are housed in an attic space, placing the insulation under the roof and treating the attic as a conditioned space is strongly recommended. This treatment allows the equipment to operate more efficiently and can prevent moisture-related problems caused by condensation on the mechanical equipment.

When insulation is placed under the roof, all vents in the attic and the intersection between the walls and roof rafters must be sealed. Rigid foam or batt insulation placed between the roof rafters is a common method of insulating the underside of a roof. Open cell spray foam (.5lb/cuft) may sometimes be applied under the roof deck only when there are no gaps in the sheathing which could allow the foam to expand under slates or shingles, preventing the re-use of the roofing material. Also, if roof leaks do occur, they may go undetected until after major damage occurs. Consideration must also be given to the irreversibility of this procedure because the foam enters the pores of the wood. It may be more advisable to install a breathable layer of material that will allow for future removal without leaving a residue.

When total roof replacement is required because of deterioration, installing rigid foam insulation on top of the roof deck before laying the new roofing material

can be simple and effective, particularly on low-pitched or flat roofs. However, the added thickness of the roof caused by installing rigid foam can alter the appearance of projecting eaves, dormers, and other features. If this application would significantly alter the appearance of these features, consider other methods.

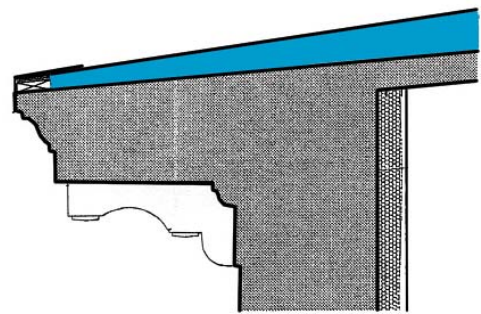


Fig. 14. Sample installation of rigid foam insulation, tapered at the edge to avoid altering the appearance of the roof.

**Install storm windows.** The addition of metal or wood exterior or interior storm windows may be advisable to increase the thermal performance of the windows in ways that weatherstripping and caulking cannot address. A single-glazed storm window may only increase a single-pane window's thermal resistance to R2, however, that is twice as good as a single-glazed window alone. It will make a noticeable contribution to the comfort level of the building occupant, with the added benefit of protecting the historic window from weathering. Using clear, non-tinted, low-e glass in the storm window can further increase the thermal performance of the window assembly without the loss of historic fabric. Studies have shown that the performance of a traditional wood window with the addition of a storm window can approach that of a double-glazed replacement window.<sup>2</sup> Some storm windows are available with insulated low-e glass, offering even higher thermal performance without the loss of the historic window. Furthermore, a storm window avoids the problem of irreparable seal failure on insulated glass units (IGUs) used in modern replacement windows. While the lifespan of the IGU depends both on the quality of the seal and other factors, it is unreasonable to expect more than 25 years. Once the seal fails, the sash itself will usually need to be entirely replaced.

By providing an additional insulating air space and adding a barrier to infiltration, storm windows improve comfort and reduce the potential for condensation on the glass. To be effective and compatible, storm windows must be tight fitting; include a sealing gasket around the glass; align with the meeting rail of the primary sash; match the color of the sash; and be caulked around the frame to reduce infiltration without interfering with any weep holes.

Whether a storm window or the historic window itself, the interior window must be the tighter of the two units to avoid condensation between the windows that can



occur in a cold climate that requires indoor heating. Condensation is a particular concern if it collects on the historic window, as can easily happen with a loose-fitting, storm window. While interior storm windows can be as thermally effective as exterior storm windows, appropriate gaskets must be used to ensure that damage-causing condensation does not form on the inside face of the historic window. Opening or removing the interior storm windows during non-heating months also helps to avoid the negative effects of moisture build-up.



*Fig. 15. Original steel windows were retained and made operable during the rehabilitation of this historic mill complex. Insulated sliding windows were added on the interior to improve energy efficiency.*

For large, steel industrial windows, the addition of interior, insulated sliding glass windows that align with the primary vertical mullions has proven to be a successful treatment that allows the primary window to remain operable.

**Insulate basements and crawlspaces.** The first step in addressing the insulation of basements and crawl spaces is to decide if they are to be part of the conditioned space and, therefore, within the thermal envelope of the building. If these areas are kept outside the thermal envelope of the building and treated as unconditioned areas, insulating between the floor joists on the underside of the subfloor is generally recommended. Alternatively, rigid foam insulation installed over the bottom of the floor joists on the basement or crawlspace side may also be used. All gaps between the unconditioned and conditioned areas of the building, including the band joists, should be air sealed to prevent air infiltration into the upper levels of the building.

If the crawlspace contains mechanical equipment, or if high levels of moist air enter the crawlspace through vents during the summer months, it is advisable to include the crawlspace within the thermal boundary of the building. As in attics, water vapor can condense on ducts and other equipment located in unconditioned basements and crawlspaces. In the past, building codes routinely required that crawlspaces be treated as non-

conditioned spaces and be ventilated. However, this has not proven to be a best practice in all cases. Ventilation through crawlspace vents does not keep the space dry during humid summers. All vents should be sealed and access doors weather-stripped. Rigid foam insulation installed on the interior face of the wall is recommended for basement and crawlspace foundation walls, only after all drainage issues have been addressed. Special attention should be given to ensure that all the joints between the insulation boards are sealed.

A moisture barrier on exposed dirt in a crawlspace is strongly recommended to prevent ground moisture from entering the building envelope. Whenever feasible, pouring a concrete slab over a moisture barrier in crawlspaces or basements with exposed dirt floors should be considered.

**Seal and insulate ducts and pipes.** A surprisingly enormous amount of energy is wasted when heated or cooled air escapes from supply ducts or when hot attic air leaks into air conditioning return ducts. Based on data collected in energy audits, as much as 35 percent of the conditioned air in an average central air conditioning system may escape from the ducts.<sup>3</sup> Care must be taken to completely seal all connections in the duct system and adequately insulate the ducts, especially in unconditioned spaces. This loss of energy is another reason to treat attics, basements and crawlspaces as conditioned spaces. Ducts located in unconditioned spaces should be insulated based on the recommendations for the appropriate climate zone. Hot water pipes and water heaters should be insulated in unconditioned spaces to retain heat, and all water pipes insulated to prevent freezing in cold climates.

**Weather strip doors and add storm doors.** Historic wood doors are often significant features and should always be retained, rather than replaced. While an insulated replacement door may have a higher R-value, doors represent a small area of the total building envelope, and the difference in energy savings after replacement would be insignificant. The doors and frames should, however, have proper maintenance including regular painting, and the addition or renewal of weatherstripping. Storm doors can improve the thermal performance of the historic door in cold climates and may be especially recommended for a door with glazing. The design of the storm door should be compatible with the character of the historic door. A fully glazed storm door with a frame that matches the color of a historic door is often an appropriate choice because it allows for the historic door to remain visible. Storm doors are recommended primarily for residential buildings. They are not appropriate for commercial or industrial buildings. These buildings never had storm doors, because the doors were opened frequently or remained open for long periods. It may also not be appropriate to install a storm door on a highly significant entrance door. In some instances,

the addition of a storm door could add significant heat gain on certain exposures or in hot climates, which could degrade the material or finish of the historic door.

**Add awnings and shading devices.** Awnings and other shading devices can provide a considerable reduction of heat gain through windows and storefronts. Keeping existing awnings, or replacing them if previously removed, is a relatively easy way to enhance the energy performance of a building. Awnings should only be installed when they are compatible with the building type and character. In building types that did not have awnings historically, interior shades, blinds or shutters should be considered instead.

A wide range of shades, blinds and shutters is available for use in all types of buildings to control heat gain or loss through windows, as well as lighting levels. When properly installed, shades are a simple and cost-effective means of saving energy. Some shade fabrics block only a portion of the light coming in — allowing the use of natural light — while others block all or most of the light. The light-colored or reflective side of the shades should face the window to reduce heat gain. Quilted roller shades feature several layers of fiber batting and sealed edges, and these shades act as both insulation and an air barrier. They control air infiltration more effectively than other soft window treatments. Pleated or cellular shades provide dead air spaces within the cells to add insulation value. These shades, however, do not measurably control air infiltration.

Retractable awnings and interior shades should be kept lowered during the summer to prevent unwanted heat gain, but raised in the winter to take advantage of the heat gain. Interior shades, especially those that have some insulation value, should be lowered at night during the winter months.

Light shelves are architectural devices designed to maximize daylight coming through windows by reflecting it deeper into the building. These horizontal elements are usually mounted on the interior above head height in buildings with high ceilings. Although they can provide energy savings, they are not compatible with most historic buildings. In general, light shelves are most likely to be appropriate in some industrial or modernist-style buildings, or where the historic integrity of interior spaces has been lost and they can be installed without being visible from the exterior.

### Requires More Alteration

**Add interior vestibules.** Vestibules that create a secondary air space or “air lock” are effective in reducing air infiltration when the exterior door is open. Exterior and interior vestibules are common architectural features of many historic buildings and should be retained wherever they exist. Adding an interior vestibule may also be appropriate in some historic buildings. For example, new glazed interior vestibules may be compatible changes to historic commercial and industrial buildings. New exterior vestibules will usually result in too great a change to the character of primary entrances, but may be acceptable in very limited instances, such as at rear entrances. Even in such instances, new vestibules should be compatible with the architectural character of the historic building.

**Replace windows.** Windows are character-defining features of most historic buildings. As discussed previously, the replacement of a historic window with a modern insulated unit is not usually a cost-effective choice. Historic wood windows have a much longer service life than replacement insulated windows, which cannot be easily repaired. Therefore, the sustainable choice is to repair historic windows and upgrade their thermal performance. However, if the historic windows are deteriorated beyond repair, if repair is impractical because of poor design or material performance, or if repair is economically infeasible, then replacement windows may be installed that match the historic windows in size, design, number of panes, muntin profile, color, reflective qualities of the glass, and the same relationship to the window opening.

Other options should also be considered before undertaking complete window replacement. If only the sash is severely deteriorated and the frame is repairable, then only the sash may need to be replaced. If the limited lifespan of insulated glass is not a concern, the new sash can be made to accommodate double glazing.



Fig. 16. Historic vestibules retain conditioned air in the living spaces.

Where the sashes are sound, but improved thermal performance without the use of a storm window is desired, some windows may be retrofitted with insulated glass. If the existing sash is of sufficient thickness, it may be routed to accept insulated, clear low-e glass without extensive loss of historic material or historic character. When insulated glass is added in a new or retrofitted sash, any weights will have to be modified to accommodate the significant extra weight.

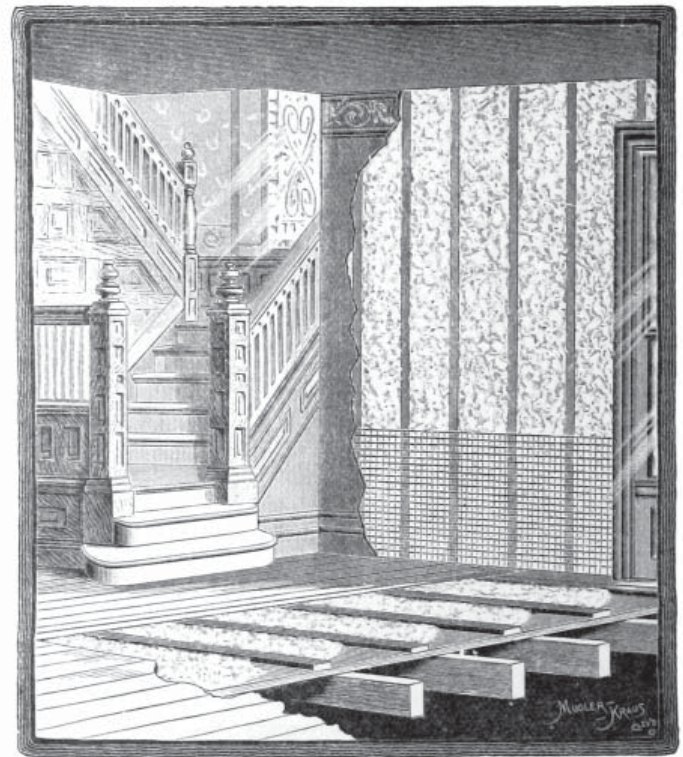
### Wall Insulation

Adding wall insulation must be evaluated as part of the overall goal to improve the thermal efficiency of a building and should only be considered after the installation of attic and basement insulation. Can this goal be achieved without the use of wall insulation? Can insulation be added without causing significant loss of historic materials or accelerated deterioration of the wall assembly? Will it be cost effective? These are basic questions that must be answered before a decision is made to insulate the walls and may require professional evaluation.

**Add insulation to wood-frame walls.** Wood is particularly susceptible to damage from high moisture levels; therefore, addressing existing moisture problems before the addition of insulation is essential. Un-insulated historic wood buildings have a higher rate of air infiltration than modern buildings; while this makes older buildings less efficient thermally, it helps dissipate the unwanted moisture and thus keeps building assemblies dry. Climate, building geometry, the condition of the building materials, construction details, and many other factors make it difficult to assess the impact that adding insulation will have on reducing the air flow and, hence, the drying rate in a particular building. For this reason, predicting the impact of adding insulation to wood-frame walls is difficult.

*Insulation Installed in the Wall Cavity:* When sheathing is part of the wall assembly, and after any moisture-related problems have been addressed, adding insulation to the interior cavity of a wood-frame wall may be considered. Adding insulation in a wall where there is no sheathing between the siding and studs is more problematic, however, because moisture entering the wall cavity through cracks and joints by wind-driven rain or capillary action will wet the insulation in contact with the back of the siding.

Installing **blown-in insulation**, either dense-packed cellulose or fiberglass, into the wall cavity causes the least amount of damage to historic materials and finishes when there is access to the cavity walls, and it is therefore a common method of insulating wood-frame walls in existing buildings. In most cases, blowing insulation material into the wall cavity requires access through the exterior or interior wall surfaces. When historic plaster, wood paneling, or other interior historic decorative elements are present, accessing the



AN INTERIOR

Showing Mineral Wool in Floor, and Walls behind Wire Lath.

*Fig. 17. Illustration of insulation from the 1889 trade catalog "The Uses of Mineral Wool in Architecture, Car Building and Steam Engineering". Collection Centre Canadien d'Architecture/Canadian Centre for Architecture, Montreal, Canada.*

cavity from the exterior is recommended by removing individual siding boards at the top of each wall cavity. In this manner the boards can be reinstalled without unsightly drill holes on the exterior. If the plaster is deteriorated and will require repair, then the wall cavity may be accessed from the interior through holes drilled through non-decorative plaster.

Of the materials available, dense-packed cellulose fiber is most commonly used. Its R-value, ability to absorb and diffuse moisture, impediment to air flow, relatively simple installation, and low cost make it a popular choice. Cellulose insulation from most manufacturers is available in at least two grades that are characterized by the type of fire retardant added to the insulation. The fire retardants are usually: (1) a mix of ammonium sulfate and boric acid or (2) boric acid only (termed "borate only"). The recommended type of cellulose insulation for historic buildings is the "borate only" grade, as cellulose treated with sulfates reacts with moisture in the air and forms sulfuric acid which corrodes many metals.

Optimum conditions for installing insulation inside the wall cavity occur in buildings where either the exterior materials or interior finishes have been lost, or where the materials are deteriorated beyond repair and total replacement is necessary. However, wholesale removal of historic materials either on the exterior or interior face of a historic wall to facilitate insulation is

not recommended. Even when the exterior materials, such as wood siding, could potentially be reinstated, this method, no matter how carefully executed, usually results in damage to, and loss of historic materials.



Fig. 18. Dense-packed cellulose insulation is being blown in through holes drilled in the sheathing. Once the operation has been completed, the shingles will be reinstalled. Photo: Edward Minch.

If the wall cavity is open, the opportunity to properly install **batt insulation** is available. A tight fit between the insulation and the adjacent building components is critical to the performance of the insulation. Batt insulation must be cut to the exact length of the cavity. A batt that is too short creates air spaces above and beneath the batt, allowing convection. A batt that is too long will bunch up, creating air pockets. Air pockets and convection currents significantly reduce the thermal performance of insulation. Each wall cavity should be completely filled. Unfaced, friction-fit batt insulation fluffed to fill the entire wall cavity is recommended. Any air gaps between the insulation and the framing or other assembly components must be avoided. Batts should be split around wiring, pipes, ducts and other elements in the wall rather than be pushed or compressed around obstacles.

When adding insulation to the sidewalls, the band joist area between floors in multi-story, platform-framed buildings should be included in the sidewall insulation retrofit. The R-value of the insulation installed in the band joist area should be at least equal to the R-value of

### Band Joist

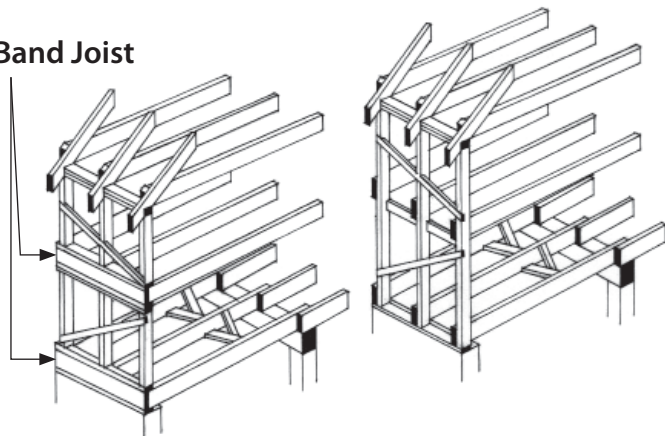


Fig. 19. Platform framing (left) and Balloon framing (right).

the insulation in the adjacent wall cavities. In balloon-framed buildings, the wall cavity is continuous between floors except where fire stops have been inserted.

The use of **spray foam or foamed-in-place insulation** would appear to have great potential for application in historic wood-frame buildings due to their ability to flow into wall cavities and around irregular obstacles. Their high R-value and function as an air barrier make them a tempting choice. However, their use presents several problems. The injected material bonds tightly to historic materials making its removal difficult, especially if it is encased in an existing wall. The pressure caused by the expansion rate of these foams within a wall can also damage historic material, including breaking the plaster keys or cracking existing plaster finishes.

*Insulation Installed on Either Side of the Wall:* Batt, rigid foam board, and spray foam insulation are commonly added to the interior face of walls in existing buildings by furring-out the walls to accommodate the additional thickness. However, this often requires the destruction or alteration of important architectural features, such as cornices, base boards, and window trim, and the removal or covering of plaster or other historic wall finishes. Insulation installed in this manner is only recommended in buildings where interior spaces and features lack architectural distinction or have lost significance due to previous alterations.



Fig. 20. The walls have been furred out inappropriately around the historic window trim creating an appearance the interior never had historically.

Adding rigid foam insulation to the exterior face of wood-frame buildings, while common practice in new construction, is never an appropriate treatment for historic buildings. Exterior installation of the foam boards requires removal of the existing siding and trim to install one or more layers of polyisocyanurate or polystyrene foam panels. Depending on the amount of insulation added for the particular climate, the wall thickness may be dramatically increased by moving

## What about moisture?

The issue of moisture in insulated assemblies is the subject of much debate. While there is no conclusive way to predict all moisture problems, especially in historic buildings, experts seem to agree on a few basic tenants. Exterior materials in insulated buildings become colder in the winter and stay wet longer following a rain event. While the wetness may not pose a problem for robust materials, it may speed the deterioration of some building materials, and lead to more frequent maintenance such as repainting of wood or repointing of masonry. Summer moisture problems are most commonly associated with excessive indoor cooling and the use of interior wall finishes that act as vapor retarders (paint buildup or vinyl wall coverings). Good air-sealing at the ceiling plane usually controls moisture in insulated attics.

Most problems are caused by poor moisture management, poor detailing which does not allow the building to shed water, or inadequate drainage. Therefore, a thorough assessment of the building's ability to keep out unwanted moisture must be done before adding new insulation materials. Refer to Preservation Brief #39: *Holding the Line: Controlling Unwanted Moisture in Historic Buildings* for more information. Because of all the uncertainties associated with insulating walls, brick walls in particular, it may be advisable to hire a professional consultant who specializes in the many factors that affect the behavior of moisture in a building and can apply this expertise to the unique characteristics of a particular structure. Sophisticated tools such as computer modeling are useful to predict the performance of building assemblies, but they require interpretation by a skilled practitioner and the results are only as good as the data entered. It is important to remember, there are no reliable prescriptive measures to prevent moisture problems.<sup>4</sup>

**Vapor Retarders (Barriers):** Vapor retardants are commonly used in modern construction to manage the diffusion of moisture into wall cavities and attics. For vapor retardants to work properly, however, they must be continuous, which makes their installation difficult in existing buildings, and therefore generally not recommended. Even in new construction, installation of vapor retardants is not always indicated. Formerly, the recommended treatment was to install a vapor retardant toward the heated side of the wall (toward the interior space in cold climates and toward the exterior in hot climates). DOE now recommends that if moisture moves both to the interior and exterior of a building for significant parts of the year, it is better not to use a vapor retarder at all.<sup>5</sup>

the siding as much as 4 inches out from the sheathing. Even if the historic siding and trim could be removed and reapplied without significant damage, the historic relationship of windows to walls, walls to eaves, and eaves to roof would be altered, which would compromise the architectural integrity and appearance of the historic building.

*Solid Masonry Walls:* As with frame buildings, installing insulation on the interior walls of a historic masonry structure should be avoided when it would involve covering or removing important architectural features and finishes, or when the added thickness would significantly alter the historic character of the interior. The addition of insulation on solid masonry walls in cold climates results in a decreased drying rate, an increased frequency of freeze-thaw cycles, and prolonged periods of warmer and colder temperatures of the masonry. These changes can have a direct effect on the durability of materials.



Fig. 21. The interior face of a brick masonry wall shows damage that resulted from the installation of a vapor retardant (foil facing) and thermal insulation. Photo: Simpson Gumpertz & Heger.

Depending on the type of masonry, exterior masonry walls can absorb a significant amount of water when it rains. Masonry walls dry both toward the exterior and the interior. When insulation is added to the interior side of a masonry wall, the insulation material reduces the drying rate of the wall toward the interior, causing the wall to stay wet for longer periods of time. Depending on the local climate, this could result in damage to the historic masonry, damage to interior finishes, and deterioration of wood or steel structural components

imbedded in the wall. Masonry walls of buildings that are heated during the winter benefit from the transfer of heat from the inside to the outside face of the walls. This thermal transfer protects the exterior face of the wall by reducing the possibility of water freezing in the outer layers of the wall, particularly in cold and wet climates. The addition of insulation on the interior of the wall not only prolongs the drying rate of the exterior masonry wall, but keeps it colder as well, thereby increasing the potential for damage due to freeze-thaw cycles.<sup>6</sup>

Extreme swings in temperature may also have negative effects on a historic masonry wall. The addition of insulation materials to a historic masonry wall decreases its ability to transfer heat; thus, walls tend to stay warm or cold for longer periods of time. In addition, walls exposed to prolonged solar radiation during winter months can also be subject to higher swings in surface temperature during the day. Deleterious effects due to stress caused by expansion and contraction of the building assembly components can result.

Buildings with masonry materials of higher porosity, such as those built with low-fired brick, or certain soft stones, are particularly susceptible to freeze-thaw cycles and must be carefully evaluated prior to adding insulation. Inspection of the masonry in areas that are not heated such as parapets, exposed wing walls, or other parts of the building is particularly important. A noticeable difference in the amount of spalling or sanding of the masonry in these areas could predict that the same type of deterioration will occur throughout the building after the walls are insulated. Brick that was fired at lower temperatures was often used on the inside face of the wall or on secondary elevations. Even masonry walls faced with more robust materials such as granite may have brick, rubble, mortar or other less durable materials as backing.

Spray foams are being used for insulation in many masonry buildings. Their ability to be applied over irregular surfaces, provide good air tightness, and continuity at intersections between, walls, ceilings, floors and window perimeters makes them well suited for use in existing buildings. However, the long-term effects of adding either open- or closed-cell foams to insulate historic masonry walls as well as performance of these products have not been adequately documented. Use of foam insulation in buildings with poor quality masonry or uncontrolled rising damp problems should be avoided.

Periodic monitoring of the condition of insulated masonry walls is strongly recommended regardless of the insulation material added.

**Install cool roofs and green roofs:** Cool roofs and vegetated “green roofs” help to reduce the heat gain from the roof, thereby cooling the building and its environment. Cool roofs include reflective metal roofs,

light-colored or white roofs, and fiberglass shingles that have a coating of reflective crystals. All of these roofing materials reflect the sun’s radiation away from the building, which lessens heat gain, resulting in a reduction of the cooling load. Cool roofs are generally not practical in northern climates where buildings benefit from the added heat gain of a dark-colored roof during colder months. Cool and green roofs are appropriate for use on historic buildings only when they are compatible with their architectural character, such as flat roofs with no visibility. A white-colored roof that is readily visible is not appropriate for historic metal roofs that were traditionally painted a dark color, such as green or iron oxide red. A white reflective roof is most suitable on flat roofed historic buildings. If a historic building has a slate roof, for example, removing the slate to install a metal roof is not a compatible treatment. It is never appropriate to remove a historic roof if the material is in good or repairable condition to install a cool roof. However, if the roof has previously been changed to an asphalt shingle roof, fiberglass shingles with special reflective granules may be an appropriate replacement.



*Fig. 22. Installation of both cool and green roofs in an urban environment.*

A green roof consists of a thin layer of vegetation planted over a waterproofing system or in trays installed on top of an existing flat or slightly sloped roof. Green roofs are primarily beneficial in urban contexts to reduce the heat island effect in cities and to control storm water run-off. A green roof also reduces the cooling load of the building and helps cool the surrounding urban environment, filters air, collects and filters storm water, and can provide urban amenities, including vegetable gardens, for building occupants. The impact of increased

structural loads, added moisture, and potential for leaks must be considered before installing a green roof. A green roof is compatible on a historic building only if the plantings are not visible above the roofline as seen from below.

## Alternative Energy Sources

Although not the focus of this publication, alternative energy sources are dealt with in more detail in *The Secretary of the Interior's Standards for Rehabilitation & Illustrated Guidelines on Sustainability for Rehabilitating Historic Buildings* and other NPS publications.

Devices that utilize solar, geothermal, wind and other sources of energy to help reduce consumption of fossil fuel-generated energy can often be successfully incorporated in historic building retrofits. However, if the alterations or costs required to install these devices do not make their installation economically feasible, buying power generated off site from renewable sources may also be a good alternative. The use of most alternative energy strategies should be pursued only after all other upgrades have been implemented to make the building more energy efficient because their initial installation cost is usually high.

**Solar Energy:** Man has sought to harness the power of solar energy to heat, cool, and illuminate buildings throughout history. Construction techniques and design strategies that utilize building materials and components to collect, store, and release heat from the sun are described as “passive solar design.” As previously discussed, many historic buildings include passive solar features that should be retained and may be enhanced. Compatible additions to historic buildings also offer opportunities to incorporate passive solar features. Active solar devices, such as solar heat collectors and photovoltaic systems, can be added to historic buildings to decrease reliance on grid-source fossil-fuel powered electricity. Incorporating active solar devices in existing buildings is becoming more common as solar collector technology advances. Adding this technology to historic buildings, however, must be done in a manner that has a minimal impact on historic roofing materials and preserves their character by placing them in locations with limited or no visibility, i.e., on flat roofs at a low angle or on a secondary roof slope.

Solar collectors used to heat water can be relatively simple. More complex solar collectors heat a fluid or air that is then pumped through the system to heat or cool interior spaces. Photovoltaic panels (PV) transform solar radiation into electricity. The greatest potential for the use of PV panels in historic buildings is on buildings with large flat roofs, high parapets, or roof configurations that allow solar panels to be installed without being prominently visible. The feasibility of installing solar devices in small commercial and residential buildings will depend on installation costs, conventional energy rates, and available incentives, all of

which will vary with time and location. The same factors apply to the use of solar collectors for heating water, but smaller installations may meet a building's need and the technology has a considerable track record.



Fig. 23. Solar collectors installed in a compatible manner on low sloping sawtooth monitors. Top Photo: Neil Mishalov, Berkeley, CA.

**Geothermal Energy:** The use of the earth's heat is another source of readily-accessible clean energy. The most common systems that utilize this form of energy are geothermal heat pumps, also known as geo-exchange, earth-coupled, ground-source, or water-source heat pumps. Introduced in the late 1940s, geothermal heat pumps rely on heat from the constant temperature of the earth, unlike most other heat pumps which use the outside air temperature as the exchange medium. This makes geothermal heat pumps more efficient than conventional heat pumps because they do not require an electric back-up heat source during prolonged periods of cold weather.

There are many reasons that geothermal heat pumps are well suited for use in historic buildings. They can reduce the amount of energy consumption and emissions considerably, compared to the air exchange systems or electric resistance heating of conventional HVAC systems. They require less equipment space, have fewer moving parts, provide better zone space conditioning, and maintain better internal humidity levels. Geothermal heat pumps are also quieter because they do not require external air compressors. Despite higher installation costs, geothermal systems offer long-term operational savings and adaptability that may make them a worthwhile investment in some historic buildings.

**Wind Energy:** For historic properties in rural areas, where wind power has been utilized historically, installation of a wind mill or turbine may be suitable to the historic setting and cost effective. Before choosing to install wind-powered equipment, the potential benefit and the impact on the historic character of the building, the site and surrounding historic district must be analyzed. In order for the turbines to work effectively, average wind speeds of 10 mph or higher are necessary. This technology may not be practical in more densely-populated areas sheltered from winds or regions where winds are not consistent. In cities with tall buildings, there is potential for installing relatively small rooftop turbines that are not visible from the ground. However, because of the initial cost and size of some turbines, it is generally more practical to purchase wind power from an off-site wind farm through the local utility company.

## Summary

With careful planning, the energy efficiency of historic buildings can be optimized without negatively impacting their historic character and integrity. Measuring the energy performance of buildings after improvements are completed must not be overlooked, as it is the only way to verify that the treatments have had the intended effect. Ongoing monitoring of buildings and their components after alterations to historic building assemblies are completed can prevent irreparable damage to historic materials. This, along with regular maintenance, can ensure the long-term preservation of our historic built environment and the sustainable use of our resources.

## End Notes

<sup>1</sup> John Krigger and Chris Dorsi, "Air Leakage," in *Residential Energy: Cost Savings and Comfort for Existing Buildings*. Helena, Montana: Saturn Resource Management, 2004, p. 73.

<sup>2</sup> *Measured Winter Performance of Storm Windows*. A 2002 study done by Lawrence Berkeley National Labs.

<sup>3</sup> *Midwest Weatherization Best Practices Field Guide*. Prepared for the U.S. Department of Energy Weatherization Assistance Program, May 2007, p. 157.

<sup>4</sup> Adapted from comments provided by William B. Rose, Research Architect, University of Illinois, April 2011.

<sup>5</sup> U.S. Department of Energy, *Insulation Fact Sheet*, DOE/CE-0180, 2008, p.14.

<sup>6</sup> Bradford S. Carpenter, P.E., LEED AP et al., *The Designer's Dilemma: Modern Performance Expectations and Historic Masonry Walls* (paper presented at the RCI 2010 Symposium on Building Envelope Technology, San Antonio, Texas).

## Acknowledgements

Jo Ellen Hensley, Senior Architectural Historian, LEED Green Associate, and Antonio Aguilar, Senior Historical Architect, Technical Preservation Services Branch, National Park Service, revised *Preservation Brief 3: Conserving Energy in Historic Buildings*, written by Baird M. Smith, FAIA and published in 1978. The revised Brief contains expanded and updated information on the subject of energy efficiency in historic buildings. A number of individuals and organizations have contributed their time and expertise in the development of this Brief, beginning with the participants of the "Improving Energy Efficiency in Historic Buildings—A Round Table Symposium," Washington, DC, 2002. Special thanks go to Mike Jackson, FAIA, Illinois Historic Preservation Agency; Edward Minch, Energy Services Group; William B. Rose, Research Architect, University of Illinois; Bradford S. Carpenter, P.E., LEED AP; and Mark Thaler, AIA, for their technical advice. The Advisory Council on Historic Preservation's Sustainability Task Force, the General Services Administration's Center for Historic Buildings, and our colleagues at the National Center for Preservation Technology and Training commented on the manuscript. In addition, the Technical Preservation Services professional staff, in particular Anne Grimmer, Michael J. Auer and John Sandor, provided critical and constructive review of the publication.

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. Additional information about the programs of Technical Preservation Services is available on the website at [www.nps.gov/tps](http://www.nps.gov/tps). Comments about this publication should be addressed to: Charles E. Fisher, Technical Preservation Publications Program Manager, Technical Preservation Services, National Park Service, 1201 Eye Street, NW, 6<sup>th</sup> Floor, Washington, DC 20005. This publication is not copyrighted and can be reproduced without penalty. Normal procedures for credit to the authors and the National Park Service are appreciated. The photographs used in this publication may not be used to illustrate other publications without permission of the owners. *Cover photograph: Farmhouse with energy efficient historic storm windows.*



# 4 PRESERVATION BRIEFS

## Roofing for Historic Buildings

Sarah M. Sweetser



U.S. Department of the Interior  
National Park Service  
Cultural Resources  
Heritage Preservation Services



HABS

### Significance of the Roof

A weather-tight roof is basic in the preservation of a structure, regardless of its age, size, or design. In the system that allows a building to work as a shelter, the roof sheds the rain, shades from the sun, and buffers the weather.

During some periods in the history of architecture, the roof imparts much of the architectural character. It defines the style and contributes to the building's aesthetics. The hipped roofs of Georgian architecture, the turrets of Queen Anne, the Mansard roofs, and the graceful slopes of the Shingle Style and Bungalow designs are examples of the use of roofing as a major design feature.

But no matter how decorative the patterning or how compelling the form, the roof is a highly vulnerable element of a shelter that will inevitably fail. A poor roof will permit the accelerated deterioration of historic building materials—masonry, wood, plaster, paint—and will cause general disintegration of the basic structure. Furthermore, there is an urgency involved in repairing a leaky roof since such repair costs will quickly become prohibitive. Although such action is desirable as soon as a failure is discovered, temporary patching methods should be carefully chosen to prevent inadvertent damage to sound or historic roofing materials and related features. Before any repair work is performed, the historic value of the materials used on the roof should be understood. Then a complete internal and external inspection of the roof should be planned to determine all the causes of failure and to identify the alternatives for repair or replacement of the roofing.

### Historic Roofing Materials in America

**Clay Tile:** European settlers used clay tile for roofing as early as the mid-17th century; many pantiles (S-curved tiles), as well as flat roofing tiles, were used in Jamestown, Virginia. In some cities such as New York and Boston, clay was popularly used as a precaution against such fire as those that engulfed London in 1666 and scorched Boston in 1679.

Tiles roofs found in the mid-18th century Moravian settlements in Pennsylvania closely resembled those found in Germany. Typically, the tiles were 14–15" long, 6–7" wide with a curved butt. A lug on the back allowed the tiles to hang on the lathing without nails or pegs. The tile surface was usually scored with finger marks to promote drainage. In the Southwest, the tile roofs of the Spanish missionaries (mission tiles) were first manufactured (ca. 1780) at the Mission San Antonio de Padua in California. These semicircular tiles were



*Repairs on this pantile roof were made with new tiles held in place with metal hangers. (Main Building, Ellis Island, New York)*

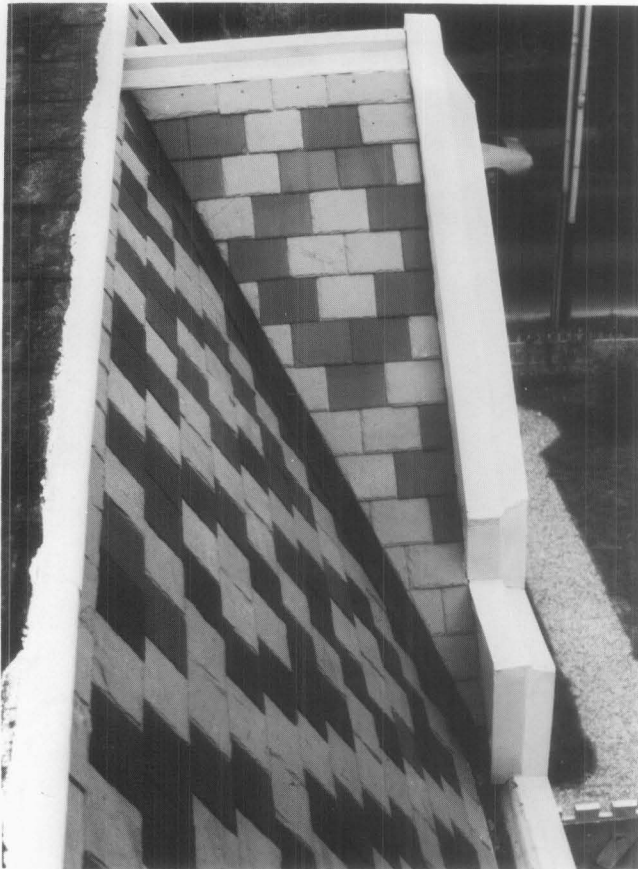
made by molding clay over sections of logs, and they were generally 22" long and tapered in width.

The plain or flat rectangular tiles most commonly used from the 17th through the beginning of the 19th century measured about 10" by 6" by 1/2", and had two holes at one end for a nail or peg fastener. Sometimes mortar was applied between the courses to secure the tiles in a heavy wind.

In the mid-19th century, tile roofs were often replaced by sheet-metal roofs, which were lighter and easier to install and maintain. However, by the turn of the century, the Romanesque Revival and Mission style buildings created a new demand and popularity for this picturesque roofing material.

**Slate:** Another practice settlers brought to the New World was slate roofing. Evidence of roofing slates have been found also among the ruins of mid-17th-century Jamestown. But because of the cost and the time required to obtain the material, which was mostly imported from Wales, the use of slate was initially limited. Even in Philadelphia (the second largest city in the English-speaking world at the time of the Revolution) slates were so rare that "The Slate Roof House" distinctly referred to William Penn's home built late in the 1600s. Sources of native slate were known to exist along the eastern seaboard from Maine to Virginia, but difficulties in inland transportation limited its availability to the cities, and contributed to its expense. Welsh slate continued to be imported until the development of canals and railroads in the mid-19th century made American slate more accessible and economical.

Slate was popular for its durability, fireproof qualities, and



*The Victorians loved to use different colored slates to create decorative patterns on their roofs, an effect which cannot be easily duplicated by substitute materials. Before any repair work on a roof such as this, the slate sizes, colors, and position of the patterning should be carefully recorded to assure proper replacement. (Ebenezer Maxwell Mansion, Philadelphia, Pennsylvania, photo courtesy of William D. Hershey)*

aesthetic potential. Because slate was available in different colors (red, green, purple, and blue-gray), it was an effective material for decorative patterns on many 19th-century roofs (Gothic and Mansard styles). Slate continued to be used well into the 20th century, notably on many Tudor revival style buildings of the 1920s.

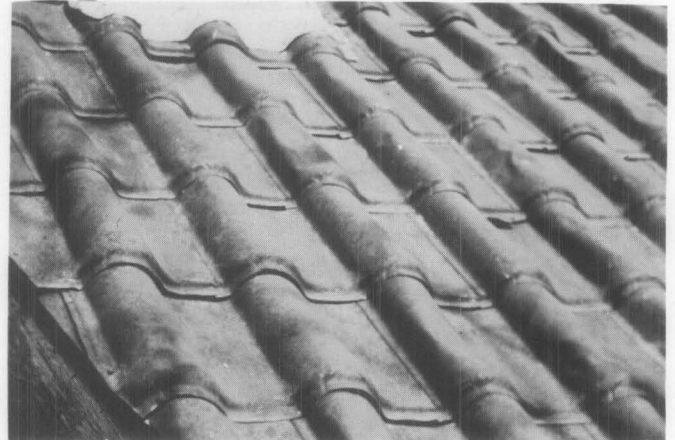
**Shingles:** Wood shingles were popular throughout the country in all periods of building history. The size and shape of the shingles as well as the detailing of the shingle roof differed according to regional craft practices. People within particular regions developed preferences for the local species of wood that most suited their purposes. In New England and the Delaware Valley, white pine was frequently used: in the South, cypress and oak; in the far west, red cedar or redwood. Sometimes a protective coating was applied to increase the durability of the shingle such as a mixture of brick dust and fish oil, or a paint made of red iron oxide and linseed oil.

Commonly in urban areas, wooden roofs were replaced with more fire resistant materials, but in rural areas this was not a major concern. On many Victorian country houses, the practice of wood shingling survived the technological advances of metal roofing in the 19th century, and near the turn of the century enjoyed a full revival in its namesake, the Shingle Style. Colonial revival and the Bungalow styles in the 20th century assured wood shingles a place as one of the most fashionable, domestic roofing materials.

**Metal:** Metal roofing in America is principally a 19th-century phenomenon. Before then the only metals commonly



*Replacement of particular historic details is important to the individual historic character of a roof, such as the treatment at the eaves of this rounded butt wood shingle roof. Also note that the surface of the roof was carefully sloped to drain water away from the side of the dormer. In the restoration, this function was augmented with the addition of carefully concealed modern metal flashing. (Mount Vernon, Virginia)*



*Galvanized sheet-metal shingles imitating the appearance of pantiles remained popular from the second half of the 19th century into the 20th century. (Episcopal Church, now the Jerome Historical Society Building, Jerome, Arizona, 1927)*

used were lead and copper. For example, a lead roof covered "Rosewell," one of the grandest mansions in 18th-century Virginia. But more often, lead was used for protective flashing. Lead, as well as copper, covered roof surfaces where wood, tile, or slate shingles were inappropriate because of the roof's pitch or shape.

Copper with standing seams covered some of the more notable early American roofs including that of Christ Church (1727-1744) in Philadelphia. Flat-seamed copper was used on many domes and cupolas. The copper sheets were imported from England until the end of the 18th century when facilities for rolling sheet metal were developed in America.

Sheet iron was first known to have been manufactured here by the Revolutionary War financier, Robert Morris, who had a rolling mill near Trenton, New Jersey. At his mill Morris produced the roof of his own Philadelphia mansion, which he started in 1794. The architect Benjamin H. Latrobe used sheet iron to replace the roof on Princeton's "Nassau Hall," which had been gutted by fire in 1802.

The method for corrugating iron was originally patented in England in 1829. Corrugating stiffened the sheets, and allowed greater span over a lighter framework, as well as reduced installation time and labor. In 1834 the American architect William Strickland proposed corrugated iron to cover his design for the market place in Philadelphia.

Galvanizing with zinc to protect the base metal from rust was developed in France in 1837. By the 1850s the material was used on post offices and customhouses, as well as on train sheds and factories. In 1857 one of the first metal roofs in the



Repeated repair with asphalt, which cracks as it hardens, has created a blistered surface on this sheet-metal roof and built-in gutter, which will retain water. Repairs could be made by carefully heating and scraping the surface clean, repairing the holes in the metal with a flexible mastic compound or a metal patch, and coating the surface with a fibre paint. (Roane County Courthouse, Kingston, Tennessee, photo courtesy of Building Conservation Technology, Inc.)

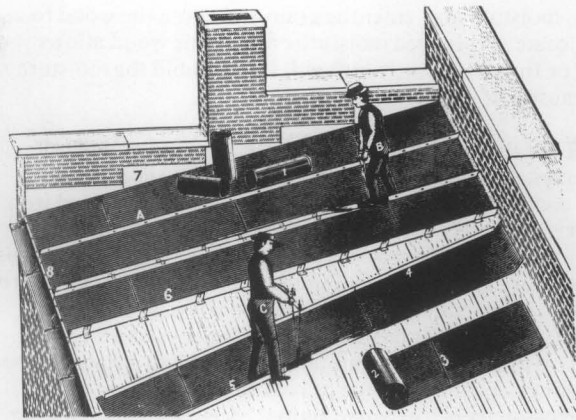
South was installed on the U.S. Mint in New Orleans. The Mint was thereby “fireproofed” with a 20-gauge galvanized, corrugated iron roof on iron trusses.

Tin-plate iron, commonly called “tin roofing,” was used extensively in Canada in the 18th century, but it was not as common in the United States until later. Thomas Jefferson was an early advocate of tin roofing, and he installed a standing-seam tin roof on “Monticello” (ca. 1770–1802). The Arch Street Meetinghouse (1804) in Philadelphia had tin shingles laid in a herringbone pattern on a “piazza” roof.

However, once rolling mills were established in this country, the low cost, light weight, and low maintenance of tin plate made it the most common roofing material. Embossed tin shingles, whose surfaces created interesting patterns, were popular throughout the country in the late 19th century. Tin roofs were kept well-painted, usually red; or, as the architect A. J. Davis suggested, in a color to imitate the green patina of copper.

Terne plate differed from tin plate in that the iron was dipped in an alloy of lead and tin, giving it a duller finish. Historic, as well as modern, documentation often confuses the two, so much that it is difficult to determine how often actual “terne” was used.

Zinc came into use in the 1820s, at the same time tin plate was becoming popular. Although a less expensive substitute for lead, its advantages were controversial, and it was never widely used in this country.



A Chicago firm’s catalog dated 1896 illustrates a method of unrolling, turning the edges, and finishing the standing seam on a metal roof.



Tin shingles, commonly embossed to imitate wood or tile, or with a decorative design, were popular as an inexpensive, textured roofing material. These shingles  $8\frac{3}{8}$  inch by  $12\frac{1}{2}$  inch on the exposed surface) were designed with interlocking edges, but they have been repaired by surface nailing, which may cause future leakage. (Ballard House, Yorktown, Virginia, photo by Gordie Whittington, National Park Service)

**Other Materials:** Asphalt shingles and roll roofing were used in the 1890s. Many roofs of asbestos, aluminum, stainless steel, galvanized steel, and lead-coated copper may soon have historic values as well. Awareness of these and other traditions of roofing materials and their detailing will contribute to more sensitive preservation treatments.

### Locating the Problem

#### Failures of Surface Materials

When trouble occurs, it is important to contact a professional, either an architect, a reputable roofing contractor, or a craftsman familiar with the inherent characteristics of the particular historic roofing system involved. These professionals may be able to advise on immediate patching procedures and help plan more permanent repairs. A thorough examination of the roof should start with an appraisal of the existing condition and quality of the roofing material itself. Particular attention should be given to any southern slope because year-round exposure to direct sun may cause it to break down first.

**Wood:** Some historic roofing materials have limited life expectancies because of normal organic decay and “wear.” For example, the flat surfaces of wood shingles erode from exposure to rain and ultraviolet rays. Some species are more hardy than others, and heartwood, for example, is stronger and more durable than sapwood.

Ideally, shingles are split with the grain perpendicular to

the surface. This is because if shingles are sawn across the grain, moisture may enter the grain and cause the wood to deteriorate. Prolonged moisture on or in the wood allows moss or fungi to grow, which will further hold the moisture and cause rot.

**Metal:** Of the inorganic roofing materials used on historic buildings, the most common are perhaps the sheet metals: lead, copper, zinc, tin plate, terne plate, and galvanized iron. In varying degrees each of these sheet metals are likely to deteriorate from chemical action by pitting or streaking. This can be caused by airborne pollutants; acid rainwater; acids from lichen or moss; alkalis found in lime mortars or portland cement, which might be on adjoining features and washes down on the roof surface; or tannic acids from adjacent wood sheathings or shingles made of red cedar or oak.

Corrosion from "galvanic action" occurs when dissimilar metals, such as copper and iron, are used in direct contact. Corrosion may also occur even though the metals are physically separated; one of the metals will react chemically against the other in the presence of an electrolyte such as rainwater. In roofing, this situation might occur when either a copper roof is decorated with iron cresting, or when steel nails are used in copper sheets. In some instances the corrosion can be prevented by inserting a plastic insulator between the dissimilar materials. Ideally, the fasteners should be a metal sympathetic to those involved.

Iron rusts unless it is well-painted or plated. Historically this problem was avoided by use of tin plating or galvanizing. But this method is durable only as long as the coating remains intact. Once the plating is worn or damaged, the exposed iron will rust. Therefore, any iron-based roofing material needs to be undercoated, and its surface needs to be kept well-painted to prevent corrosion.

One cause of sheet metal deterioration is fatigue. Depending upon the size and the gauge of the metal sheets, wear and metal failure can occur at the joints or at any protrusions in the sheathing as a result from the metal's alternating movement to thermal changes. Lead will tear because of "creep," or the gravitational stress that causes the material to move down the roof slope.

**Slate:** Perhaps the most durable roofing materials are slate and tile. Seemingly indestructible, both vary in quality. Some slates are hard and tough without being brittle. Soft slates are more subject to erosion and to attack by airborne and rain-

water chemicals, which cause the slates to wear at nail holes, to delaminate, or to break. In winter, slate is very susceptible to breakage by ice, or ice dams.

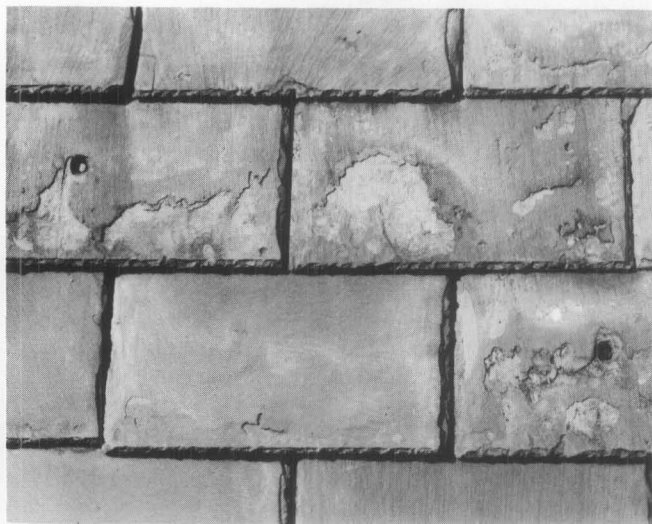
**Tile:** Tiles will weather well, but tend to crack or break if hit, as by tree branches, or if they are walked on improperly. Like slates, tiles cannot support much weight. Low quality tiles that have been insufficiently fired during manufacture, will craze and spall under the effects of freeze and thaw cycles on their porous surfaces.

#### Failures of Support Systems

Once the condition of the roofing material has been determined, the related features and support systems should be examined on the exterior and on the interior of the roof. The gutters and downspouts need periodic cleaning and maintenance since a variety of debris fill them, causing water to back up and seep under roofing units. Water will eventually cause fasteners, sheathing, and roofing structure to deteriorate. During winter, the daily freeze-thaw cycles can cause ice floes to develop under the roof surface. The pressure from these ice floes will dislodge the roofing material, especially slates, shingles, or tiles. Moreover, the buildup of ice dams above the gutters can trap enough moisture to rot the sheathing or the structural members.

Many large public buildings have built-in gutters set within the perimeter of the roof. The downspouts for these gutters may run within the walls of the building, or drainage may be through the roof surface or through a parapet to exterior downspouts. These systems can be effective if properly maintained; however, if the roof slope is inadequate for good runoff, or if the traps are allowed to clog, rainwater will form pools on the roof surface. Interior downspouts can collect debris and thus back up, perhaps leaking water into the surrounding walls. Exterior downspouts may fill with water, which in cold weather may freeze and crack the pipes. Conduits from the built-in gutter to the exterior downspout may also leak water into the surrounding roof structure or walls.

Failure of the flashing system is usually a major cause of roof deterioration. Flashing should be carefully inspected for failure caused by either poor workmanship, thermal stress, or metal deterioration (both of flashing material itself and of the fasteners). With many roofing materials, the replacement of flashing on an existing roof is a major operation, which may require taking up large sections of the roof surface. Therefore, the installation of top quality flashing material on



*This detail shows slate delamination caused by a combination of weathering and pollution. In addition, the slates have eroded around the repair nails, incorrectly placed in the exposed surface of the slates. (Lower Pontalba Building, New Orleans, photo courtesy of Building Conservation Technology, Inc.)*



*Temporary stabilization or "mothballing" with materials such as plywood and building paper can protect the roof of a project until it can be properly repaired or replaced. (Narbonne House, Salem, Massachusetts)*



*These two views of the same house demonstrate how the use of a substitute material can drastically affect the overall character of a structure. The textural interest of the original tile roof was lost with the use of asphalt shingles. Recent preservation efforts are replacing the tile roof. (Frank House, Kearney, Nebraska, photo courtesy of the Nebraska State Historical Society, Lincoln, Nebraska)*

a new or replaced roof should be a primary consideration. Remember, some roofing and flashing materials are not compatible.

Roof fasteners and clips should also be made of a material compatible with all other materials used, or coated to prevent rust. For example, the tannic acid in oak will corrode iron nails. Some roofs such as slate and sheet metals may fail if nailed too rigidly.

If the roof structure appears sound and nothing indicates recent movement, the area to be examined most closely is the roof substrate—the sheathing or the battens. The danger spots would be near the roof plates, under any exterior patches, at the intersections of the roof planes, or at vertical surfaces such as dormers. Water penetration, indicating a breach in the roofing surface or flashing, should be readily apparent, usually as a damp spot or stain. Probing with a small pen knife may reveal any rot which may indicate previously undetected damage to the roofing membrane. Insect infestation evident by small exit holes and frass (a sawdust-like debris) should also be noted. Condensation on the underside of the roofing is undesirable and indicates improper ventilation. Moisture will have an adverse effect on any roofing material; a good roof stays dry inside and out.

### Repair or Replace

Understanding potential weaknesses of roofing material also requires knowledge of repair difficulties. Individual slates can be replaced normally without major disruption to the rest of the roof, but replacing flashing on a slate roof can require substantial removal of surrounding slates. If it is the substrate or a support material that has deteriorated, many surface materials such as slate or tile can be reused if handled carefully during the repair. Such problems should be evaluated at the outset of any project to determine if the roof can be effectively patched, or if it should be completely replaced.

Will the repairs be effective? Maintenance costs tend to multiply once trouble starts. As the cost of labor escalates, repeated repairs could soon equal the cost of a new roof.

The more durable the surface is initially, the easier it will be to maintain. Some roofing materials such as slate are expensive to install, but if top quality slate and flashing are used, it will last 40–60 years with minimal maintenance. Although the installation cost of the roof will be high, low maintenance needs will make the lifetime cost of the roof less expensive.

### Historical Research

In a restoration project, research of documents and physical investigation of the building usually will establish the roof's history. Documentary research should include any original plans or building specifications, early insurance surveys, newspaper descriptions, or the personal papers and files of people who owned or were involved in the history of the building. Old photographs of the building might provide evidence of missing details.

Along with a thorough understanding of any written history of the building, a physical investigation of the roofing and its structure may reveal information about the roof's construction history. Starting with an overall impression of the structure, are there any changes in the roof slope, its configuration, or roofing materials? Perhaps there are obvious patches or changes in patterning of exterior brickwork where a gable roof was changed to a gambrel, or where a whole upper story was added. Perhaps there are obvious stylistic changes in the roof line, dormers, or ornamentation. These observations could help one understand any important alteration, and could help establish the direction of further investigation.

Because most roofs are physically out of the range of careful scrutiny, the "principle of least effort" has probably limited the extent and quality of previous patching or replacing, and usually considerable evidence of an earlier roof surface remains. Sometimes the older roof will be found as an underlayment of the current exposed roof. Original roofing may still be intact in awkward places under later features on a roof. Often if there is any unfinished attic space, remnants of roofing may have been dropped and left when the roof was being built or repaired. If the configuration of the roof has been changed, some of the original material might still be in place under the existing roof. Sometimes whole sections of the roof and roof framing will have been left intact under the higher roof. The profile and/or flashing of the earlier roof may be apparent on the interior of the walls at the level of the alteration. If the sheathing or lathing appears to have survived changes in the roofing surface, they may contain evidence of the roofing systems. These may appear either as dirt marks, which provide "shadows" of a roofing material, or as nails broken or driven down into the wood, rather than pulled out during previous alterations or repairs. Wooden headers in the roof framing may indicate that earlier chimneys or skylights have been removed. Any metal ornamentation that might have existed may be indicated by anchors or unusual markings along the ridge or at other edges of the roof. This primary

evidence is essential for a full understanding of the roof's history.

Caution should be taken in dating early "fabric" on the evidence of a single item, as recycling of materials is not a mid-20th-century innovation. Carpenters have been reusing materials, sheathing, and framing members in the interest of economy for centuries. Therefore, any analysis of the materials found, such as nails or sawmarks on the wood, requires an accurate knowledge of the history of local building practices before any final conclusion can be accurately reached. It is helpful to establish a sequence of construction history for the roof and roofing materials; any historic fabric or pertinent evidence in the roof should be photographed, measured, and recorded for future reference.

During the repair work, useful evidence might unexpectedly appear. It is essential that records be kept of any type of work on a historic building, before, during, and after the project. Photographs are generally the easiest and fastest method, and should include overall views and details at the gutters, flashing, dormers, chimneys, valleys, ridges, and eaves. All photographs should be immediately labeled to insure accurate identification at a later date. Any patterning or design on the roofing deserves particular attention. For example, slate roofs are often decorative and have subtle changes in size, color, and texture, such as a gradually decreasing coursing length from the eave to the peak. If not carefully noted before a project begins, there may be problems in replacing the surface. The standard reference for this phase of the work is *Recording Historic Buildings*, compiled by Harley J. McKee for the Historic American Buildings Survey, National Park Service, Washington, D.C., 1970.

#### Replacing the Historic Roofing Material

Professional advice will be needed to assess the various aspects of replacing a historic roof. With some exceptions, most historic roofing materials are available today. If not, an architect or preservation group who has previously worked with the same type material may be able to recommend suppliers. Special roofing materials, such as tile or embossed metal shingles, can be produced by manufacturers of related products that are commonly used elsewhere, either on the exterior or interior of a structure. With some creative thinking and research, the historic materials usually can be found.



*Because of the roof's visibility, the slate detailing around the dormers is important to the character of this structure. Note how the slates swirl from a horizontal pattern on the main roof to a diamond pattern on the dormer roofs and side walls. (18th and Que Streets, NW, Washington, D.C.)*

**Craft Practices:** Determining the craft practices used in the installation of a historic roof is another major concern in roof restoration. Early builders took great pride in their work, and experience has shown that the "rustic" or irregular designs commercially labeled "Early American" are a 20th-century invention. For example, historically, wood shingles underwent several distinct operations in their manufacture including splitting by hand, and smoothing the surface with a draw knife. In modern nomenclature, the same item would be a "tapersplit" shingle which has been dressed. Unfortunately, the rustic appearance of today's commercially available "handsplit" and re-sawn shingle bears no resemblance to the hand-made roofing materials used on early American buildings.



*Good design and quality materials for the roof surface, fastenings, and flashing minimize roofing failures. This is essential on roofs such as on the National Cathedral where a thorough maintenance inspection and minor repairs cannot be done easily without special scaffolding. However, the success of the roof on any structure depends on frequent cleaning and repair of the gutter system. (Washington, D.C., photo courtesy of John Burns, A.I.A.)*

Early craftsmen worked with a great deal of common sense; they understood their materials. For example they knew that wood shingles should be relatively narrow; shingles much wider than about 6" would split when walked on, or they may curl or crack from varying temperature and moisture. It is important to understand these aspects of craftsmanship, remembering that people wanted their roofs to be weather-tight and to last a long time. The recent use of "mother-goose" shingles on historic structures is a gross underestimation of the early craftsman's skills.

**Supervision:** Finding a modern craftsman to reproduce historic details may take some effort. It may even involve some special instruction to raise his understanding of certain historic craft practices. At the same time, it may be pointless (and expensive) to follow historic craft practices in any construction that will not be visible on the finished product. But if the roofing details are readily visible, their appearance should be based on architectural evidence or on historic prototypes. For instance, the spacing of the seams on a standing-seam metal roof will affect the building's overall scale and should therefore match the original dimensions of the seams.

Many older roofing practices are no longer performed because of modern improvements. Research and review of specific detailing in the roof with the contractor before beginning the project is highly recommended. For example, one early craft practice was to finish the ridge of a wood shingle roof with a roof "comb"—that is, the top course of one slope of the roof was extended uniformly beyond the peak to shield the ridge, and to provide some weather protection for the raw horizontal edges of the shingles on the other slope. If the "comb" is known to have been the correct detail, it should be used. Though this method leaves the top course vulnerable to the weather, a disguised strip of flashing will strengthen this weak point.

Detail drawings or a sample mock-up will help ensure that the contractor or craftsman understands the scope and special requirements of the project. It should never be assumed that the modern carpenter, slater, sheet metal worker, or roofer will know all the historic details. Supervision is as important as any other stage of the process.



*Special problems inherent in the design of an elaborate historic roof can be controlled through the use of good materials and regular maintenance. The shape and detailing are essential elements of the building's historic character, and should not be modified, despite the use of alternative surface materials. (Gamwell House, Bellingham, Washington)*

#### **Alternative Materials**

The use of the historic roofing material on a structure may be restricted by building codes or by the availability of the materials, in which case an appropriate alternative will have to be found.

Some municipal building codes allow variances for roofing materials in historic districts. In other instances, individual variances may be obtained. Most modern heating and cooking is fueled by gas, electricity, or oil—none of which emit the hot embers that historically have been the cause of roof fires. Where wood burning fireplaces or stoves are used, spark arrestor screens at the top of the chimneys help to prevent flaming material from escaping, thus reducing the number of fires that start at the roof. In most states, insurance rates have been equalized to reflect revised considerations for the risks involved with various roofing materials.

In a rehabilitation project, there may be valid reasons for replacing the roof with a material other than the original. The historic roofing may no longer be available, or the cost of obtaining specially fabricated materials may be prohibitive. But

the decision to use an alternative material should be weighed carefully against the primary concern to keep the historic character of the building. If the roof is flat and is not visible from any elevation of the building, and if there are advantages to substituting a modern built-up composition roof for what might have been a flat metal roof, then it may make better economic and construction sense to use a modern roofing method. But if the roof is readily visible, the alternative material should match as closely as possible the scale, texture, and coloration of the historic roofing material.

Asphalt shingles or ceramic tiles are common substitute materials intended to duplicate the appearance of wood shingles, slates, or tiles. Fire-retardant, treated wood shingles are currently available. The treated wood tends, however, to be brittle, and may require extra care (and expense) to install. In some instances, shingles laid with an interlay of fire-retardant building paper may be an acceptable alternative.

Lead-coated copper, terne-coated steel, and aluminum/zinc-coated steel can successfully replace tin, terne plate, zinc, or lead. Copper-coated steel is a less expensive (and less durable) substitute for sheet copper.

The search for alternative roofing materials is not new. As early as the 18th century, fear of fire cause many wood shingle or board roofs to be replaced by sheet metal or clay tile. Some historic roofs were failures from the start, based on over-ambitious and naive use of materials as they were first developed. Research on a structure may reveal that an inadequately designed or a highly combustible roof was replaced early in its history, and therefore restoration of a later roof material would have a valid precedent. In some cities, the substitution of sheet metal on early row houses occurred as soon as the rolled material became available.

Cost and ease of maintenance may dictate the substitution of a material wholly different in appearance from the original. The practical problems (wind, weather, and roof pitch) should be weighed against the historical consideration of scale, texture, and color. Sometimes the effect of the alternative material will be minimal. But on roofs with a high degree of visibility and patterning or texture, the substitution may seriously alter the architectural character of the building.

#### **Temporary Stabilization**

It may be necessary to carry out an immediate and temporary stabilization to prevent further deterioration until research can determine how the roof should be restored or rehabilitated, or until funding can be provided to do a proper job. A simple covering of exterior plywood or roll roofing might provide adequate protection, but any temporary covering should be applied with caution. One should be careful not to overload the roof structure, or to damage or destroy historic evidence or fabric that might be incorporated into a new roof at a later date. In this sense, repairs with caulking or bituminous patching compounds should be recognized as potentially harmful, since they are difficult to remove, and at their best, are very temporary.

#### **Precautions**

The architect or contractor should warn the owner of any precautions to be taken against the specific hazards in installing the roofing material. Soldering of sheet metals, for instance, can be a fire hazard, either from the open flame or from overheating and undetected smoldering of the wooden substrate materials.

Thought should be given to the design and placement of any modern roof appurtenances such as plumbing stacks, air vents, or TV antennas. Consideration should begin with the placement of modern plumbing on the interior of the building, otherwise a series of vent stacks may pierce the roof membrane at various spots creating maintenance problems as well as aesthetic ones. Air handling units placed in the attic space will require vents which, in turn, require sensitive design. Incorporating these in unused chimneys has been very successful

in the past.

Whenever gutters and downspouts are needed that were not on the building historically, the additions should be made as unobtrusively as possible, perhaps by painting them out with a color compatible with the nearby wall or trim.

### Maintenance

Although a new roof can be an object of beauty, it will not be protective for long without proper maintenance. At least twice a year, the roof should be inspected against a checklist. All changes should be recorded and reported. Guidelines should be established for any foot traffic that may be required for the maintenance of the roof. Many roofing materials should not be walked on at all. For some—slate, asbestos, and clay tile—a self-supporting ladder might be hung over the ridge of the roof, or planks might be spanned across the roof surface. Such items should be specifically designed and kept in a storage space accessible to the roof. If exterior work ever requires hanging scaffolding, use caution to insure that the anchors do not penetrate, break, or wear the roofing surface, gutters, or flashing.

Any roofing system should be recognized as a membrane that is designed to be self-sustaining, but that can be easily damaged by intrusions such as pedestrian traffic or fallen tree branches. Certain items should be checked at specific times. For example, gutters tend to accumulate leaves and debris during the spring and fall and after heavy rain. Hidden gutter screening both at downspouts and over the full length of the gutter could help keep them clean. The surface material would require checking after a storm as well. Periodic checking of the underside of the roof from the attic after a storm or winter freezing may give early warning of any leaks. Generally, damage from water or ice is less likely on a roof that has good flashing on the outside and is well ventilated and insulated on the inside. Specific instructions for the maintenance of the different roof materials should be available from the architect or contractor.

### Summary

The essential ingredients for replacing and maintaining a historic roof are:

- Understanding the historic character of the building and being sympathetic to it.
- Careful examination and recording of the existing roof and any evidence of earlier roofs.
- Consideration of the historic craftsmanship and detailing and implementing them in the renewal wherever visible.
- Supervision of the roofers or maintenance personnel to assure preservation of historic fabric and proper understanding of the scope and detailing of the project.
- Consideration of alternative materials where the original cannot be used.
- Cyclical maintenance program to assure that the staff understands how to take care of the roof and of the particular trouble spots to safeguard.

With these points in mind, it will be possible to preserve the architectural character and maintain the physical integrity of the roofing on a historic building.

This Preservation Brief was written by Sarah M. Sweetser, Architectural Historian, Technical Preservation Services Division. Much of the technical information was based upon an unpublished report prepared under contract for this office by John G. and Dianá S. Waite. Some of the historical information was from Charles E. Peterson, FAIA, "American Notes," *Journal of the Society of Architectural Historians*.

The illustrations for this brief not specifically credited are from the files of the Technical Preservation Services Division.

This publication was prepared pursuant to Executive Order 11593, "Protection and Enhancement of the Cultural Environment," which directs the Secretary of the Interior to "develop and make available to Federal agencies and State and local governments information concerning professional methods and tech-



Decorative features such as cupolas require extra maintenance. The flashing is carefully detailed to promote run-off, and the wooden ribbing must be kept well-painted. This roof surface, which was originally tin plate, has been replaced with lead-coated copper for maintenance purposes. (Lyndhurst, Tarrytown, New York, photo courtesy of the National Trust for Historic Preservation)

niques for preserving, improving, restoring and maintaining historic properties." The Brief has been developed under the technical editorship of Lee H. Nelson, AIA, Chief, Preservation Assistance Division, National Park Service, U.S. Department of the Interior, Washington, D.C. 20240. Comments on the usefulness of this information are welcome and can be sent to Mr. Nelson at the above address. This publication is not copyrighted and can be reproduced without penalty. Normal procedures for credit to the author and the National Park Service are appreciated. February 1978.

Additional readings on the subject of roofing are listed below.

- Boaz, Joseph N., ed. *Architectural Graphic Standards*. New York: John Wiley and Sons, Inc., 1970. (Modern roofing types and detailing)
- Briggs, Martin S. *A Short History of the Building Crafts*. London: Oxford University Press, 1925. (Descriptions of historic roofing materials)
- Bulletin of the Association for Preservation Technology*. Vol. 2 (nos. 1-2) 1970. (Entirely on roofing)
- Holstrom, Ingmar; and Sandstrom, Christina. *Maintenance of Old Buildings: Preservation from the Technical and Antiquarian Standpoint*. Stockholm: National Swedish Building Research, 1972. (Contains a section on roof maintenance problems)
- Insall, Donald. *The Care of Old Buildings Today*. London: The Architectural Press, 1972. (Excellent guide to some problems and solutions for historic roofs)
- Labine, R.A. Clem. "Repairing Slate Roofs." *The Old House Journal* 3 (no. 12, Dec. 1975): 6-7.
- Lefler, Henry. "A Birds-eye View." *Progressive Architecture*. (Mar. 1977), pp. 88-92. (Article on contemporary sheet metal)
- National Slate Association. *Slate Roofs*. Reprint of 1926 edition, now available from the Vermont Structural Slate Co., Inc., Fairhaven, VT 05743. (An excellent reference for the many designs and details of slate roofs)
- Peterson, Charles E. "Iron in Early American Roofs." *The Smithsonian Journal of History* 3 (no. 3). Edited by Peter C. Welsh. Washington, D.C.: Smithsonian Institution, 1968, pp. 41-76.
- Waite, Diana S. *Nineteenth Century Tin Roofing and its Use at Hyde Hall*. Albany: New York State Historic Trust, 1971.
- . "Roofing for Early America." *Building Early America*. Edited by Charles E. Peterson. Radnor, Penn.: Chilton Book Co., 1976.



# 13 PRESERVATION BRIEFS

## The Repair and Thermal Upgrading of Historic Steel Windows

Sharon C. Park, AIA



U.S. Department of the Interior  
National Park Service  
Cultural Resources  
Heritage Preservation Services



The Secretary of the Interior's "Standards for Rehabilitation" require that where historic windows are individually significant features, or where they contribute to the character of significant facades, their distinguishing visual qualities must not be destroyed. Further, the rehabilitation guidelines recommend against changing the historic appearance of windows through the use of inappropriate designs, materials, finishes, or colors which radically change the sash, depth of reveal, and muntin configuration; the reflectivity and color of the glazing; or the appearance of the frame.

Windows are among the most vulnerable features of historic buildings undergoing rehabilitation. This is especially the case with rolled steel windows, which are often mistakenly not deemed worthy of preservation in the conversion of old buildings to new uses. The ease with which they can be replaced and the mistaken assumption that they cannot be made energy efficient except at great expense are factors that typically lead to the decision to remove them. In many cases, however, repair and retrofit of the historic windows are more economical than wholesale replacement, and all too often, replacement units are unlike the originals in design and appearance. If the windows are important in establishing the historic character of the building (see fig. 1), insensitively designed replacement windows may diminish—or destroy—the building's historic character.

This *Brief* identifies various types of historic steel windows that dominated the metal window market from 1890-1950. It then gives criteria for evaluating deterioration and for determining appropriate treatment, ranging from routine maintenance and weatherization to extensive repairs, so that replacement may be avoided where possible.<sup>1</sup> This information applies to do-it-yourself jobs and to large rehabilitations where the volume of work warrants the removal of all window units for complete overhaul by professional contractors.

This *Brief* is not intended to promote the repair of ferrous metal windows in every case, but rather to insure that preservation is always the first consideration in a rehabilitation project. Some windows are not important elements in defining a building's historic character; others are highly significant, but so deteriorated that repair is infeasible. In such cases, the *Brief* offers guidance in evaluating appropriate replacement windows.



*Fig. 1 Often highly distinctive in design and craftsmanship, rolled steel windows play an important role in defining the architectural character of many later nineteenth and early twentieth century buildings. Art Deco, Art Moderne, the International Style, and Post World War II Modernism depended on the slim profiles and streamlined appearance of metal windows for much of their impact. Photo: William G. Johnson.*

<sup>1</sup>The technical information given in this brief is intended for most ferrous (or magnetic) metals, particularly rolled steel. While stainless steel is a ferrous metal, the cleaning and repair techniques outlined here must not be used on it as the finish will be damaged. For information on cleaning stainless steel and non-ferrous metals, such as bronze, Monel, or aluminum, refer to *Metals in America's Historic Buildings* (see bibliography).

## HISTORICAL DEVELOPMENT

Although metal windows were available as early as 1860 from catalogues published by architectural supply firms, they did not become popular until after 1890. Two factors combined to account for the shift from wooden to metal windows about that time. Technology borrowed from the rolling industry permitted the mass production of rolled steel windows. This technology made metal windows cost competitive with conventional wooden windows. In addition, a series of devastating urban fires in Boston, Baltimore, Philadelphia, and San Francisco led to the enactment of strict fire codes for industrial and multi-story commercial and office buildings.

As in the process of making rails for railroads, rolled steel windows were made by passing hot bars of steel through progressively smaller, shaped rollers until the appropriate angled configuration was achieved (see fig. 2). The rolled steel sections, generally 1/8" thick and 1" - 1 1/2" wide, were used for all the components of the windows: sash, frame, and subframe (see fig. 3). With the addition of wire glass, a fire-resistant window resulted. These rolled steel windows are almost exclusively found in masonry or concrete buildings.

A byproduct of the fire-resistant window was the strong metal frame that permitted the installation of larger windows and windows in series. The ability to have expansive amounts of glass and increased ventilation dramatically changed the designs of late 19th and early 20th century industrial and commercial buildings.

The newly available, reasonably priced steel windows soon became popular for more than just their fire-resistant qualities. They were standardized, extremely durable, and easily transported. These qualities led to the use of steel windows in every type of construction, from simple industrial and institutional buildings to luxury commercial and apartment buildings. Casement, double-hung, pivot, projecting, austral, and continuous windows differed in operating and ventilating capacities. Figure 4 outlines the kinds and properties of metal windows available then and now. In addition, the thin profiles of metal windows contributed to the streamlined appearance of the Art Deco, Art Moderne, and International Styles, among others.

The extensive use of rolled steel metal windows continued until after World War II when cheaper, non-corroding aluminum windows became increasingly popular. While aluminum windows dominate the market today, steel windows are still fabricated. Should replacement of original windows become necessary, replacement windows may be available from the manufacturers of some of the earliest steel windows. Before an informed decision can be made whether to repair or replace metal windows, however, the significance of the windows must be determined and their physical condition assessed.

ROLLING SECTION FROM BAR

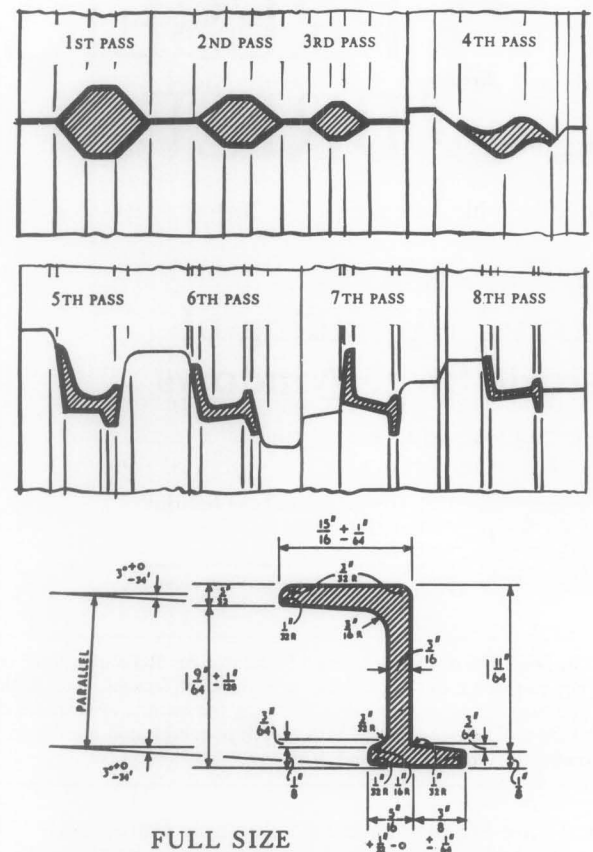


Fig. 2. The process of rolling a steel bar into an angled section is illustrated above. The shape and size of the rolled section will vary slightly depending on the overall strength needed for the window opening and the location of the section in the assembly: subframe, frame, or sash. The 1/8" thickness of the metal section is generally standard. Drawing: *A Metal Window Dictionary*. Used with permission.

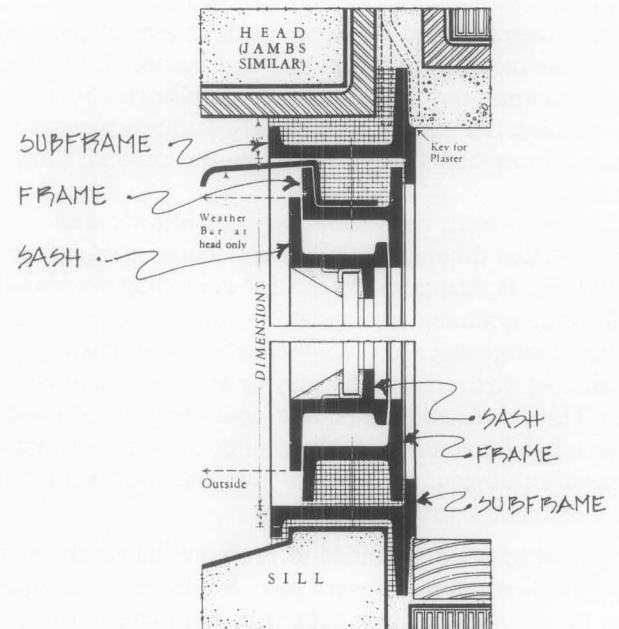


Fig. 3 A typical section through the top and bottom of a metal window shows the three component parts of the window assembly: subframe, frame, and sash. Drawings: *Catalogue No. 15, January 1931; International Casement Co, Inc., presently Hope's Architectural Products, Inc., Jamestown, NY*. Used with permission.

## EVALUATION

### Historic and Architectural Considerations

An assessment of the significance of the windows should begin with a consideration of their function in relation to the building's historic use and its historic character. Windows that help define the building's historic character should be preserved even if the building is being converted to a new use. For example, projecting steel windows used to introduce light and an effect of spaciousness to a warehouse or industrial plant can be retained in the conversion of such a building to offices or residences.

Other elements in assessing the relative importance of the historic windows include the design of the windows and their relationship to the scale, proportion, detailing and architectural style of the building. While it may be easy to determine the aesthetic value of highly ornamented windows, or to recognize the importance of streamlined windows as an element of a style, less elaborate windows can also provide strong visual interest by their small panes or projecting planes when open, particularly in simple, unadorned industrial buildings (see fig. 5).

One test of the importance of windows to a building is to ask if the overall appearance of the building would be changed noticeably if the windows were to be removed or radically altered. If so, the windows are important in defining the building's historic character, and should be repaired if their physical condition permits.

### Physical Evaluation

Steel window repair should begin with a careful evaluation of the physical condition of each unit. Either drawings or photographs, liberally annotated, may be used to record the location of each window, the type of operability, the condition of all three parts—sash, frame and sub-frame—and the repairs essential to its continued use.

Specifically, the evaluation should include: presence and degree of corrosion; condition of paint; deterioration of the metal sections, including bowing, misalignment of the sash, or bent sections; condition of the glass and glazing compound; presence and condition of all hardware, screws, bolts, and hinges; and condition of the masonry or concrete surrounds, including need for caulking or resetting of improperly sloped sills.

Corrosion, principally rusting in the case of steel windows, is the controlling factor in window repair; therefore, the evaluator should first test for its presence. Corrosion can be light, medium, or heavy, depending on how much the rust has penetrated the metal sections. If the rusting is merely a surface accumulation or flaking, then the corrosion is light. If the rusting has penetrated the metal (indicated by a bubbling texture), but has not caused any structural damage, then the corrosion is medium. If the rust has penetrated deep into the metal, the corrosion is heavy. Heavy corrosion generally results in some form of structural damage, through delamination,

to the metal section, which must then be patched or spliced. A sharp probe or tool, such as an ice pick, can be used to determine the extent of corrosion in the metal. If the probe can penetrate the surface of the metal and brittle strands can be dug out, then a high degree of corrosive deterioration is present.

In addition to corrosion, the condition of the paint, the presence of bowing or misalignment of metal sections, the amount of glass needing replacement, and the condition of the masonry or concrete surrounds must be assessed in the evaluation process. These are key factors in determining whether or not the windows can be repaired in place. The more complete the inventory of existing conditions, the easier it will be to determine whether repair is feasible or whether replacement is warranted.

### Rehabilitation Work Plan

Following inspection and analysis, a plan for the rehabilitation can be formulated. The actions necessary to return windows to an efficient and effective working condition will fall into one or more of the following categories: routine maintenance, repair, and weatherization. The routine maintenance and weatherization measures described here are generally within the range of do-it-yourselfers. Other repairs, both moderate and major, require a professional contractor. Major repairs normally require the removal of the window units to a workshop, but even in the case of moderate repairs, the number of windows involved might warrant the removal of all the deteriorated units to a workshop in order to realize a more economical repair price. Replacement of windows should be considered only as a last resort.

Since moisture is the primary cause of corrosion in steel windows, it is essential that excess moisture be eliminated and that the building be made as weathertight as possible before any other work is undertaken. Moisture can accumulate from cracks in the masonry, from spalling mortar, from leaking gutters, from air conditioning condensation runoff, and from poorly ventilated interior spaces.

Finally, before beginning any work, it is important to be aware of health and safety risks involved. Steel windows have historically been coated with lead paint. The removal of such paint by abrasive methods will produce toxic dust. Therefore, safety goggles, a toxic dust respirator, and protective clothing should be worn. Similar protective measures should be taken when acid compounds are used. Local codes may govern the methods of removing lead paints and proper disposal of toxic residue.

### ROUTINE MAINTENANCE

A preliminary step in the routine maintenance of steel windows is to remove surface dirt and grease in order to ascertain the degree of deterioration, if any. Such minor cleaning can be accomplished using a brush or vacuum followed by wiping with a cloth dampened with mineral spirits or denatured alcohol.

<p><i>Double-hung</i> industrial windows duplicated the look of traditional wooden windows. Metal double-hung windows were early examples of a building product adapted to meet stringent new fire code requirements for manufacturing and high-rise buildings in urban areas. Soon supplanted in industrial buildings by less expensive pivot windows, double-hung metal windows regained popularity in the 1940s for use in speculative suburban housing.</p>	<p><i>Austral</i> windows were also a product of the 1920s. They combined the appearance of the double-hung window with the increased ventilation and ease of operation of the projected window. (When fully opened, they provided 70% ventilation as compared to 50% ventilation for double-hung windows.) Austral windows were often used in schools, libraries and other public buildings.</p>
<p><i>Pivot</i> windows were an early type of industrial window that combined inexpensive first cost and low maintenance. Pivot windows became standard for warehouses and power plants where the lack of screens was not a problem. The window shown here is a horizontal pivot. Windows that turned about a vertical axis were also manufactured (often of iron). Such vertical pivots are rare today.</p>	<p><i>Casement</i> windows adapted the English tradition of using wrought iron casements with leaded cames for residential use. Rolled steel casements (either single, as shown, or paired) were popular in the 1920s for cottage style residences and Gothic style campus architecture. More streamlined casements were popular in the 1930s for institutional and small industrial buildings.</p>
<p><i>Projecting</i> windows, sometimes called awning or hopper windows, were perfected in the 1920s for industrial and institutional buildings. They were often used in "combination" windows, in which upper panels opened out and lower panels opened in. Since each movable panel projected to one side of the frame only, unlike pivot windows, for example, screens could be introduced.</p>	<p><i>Continuous</i> windows were almost exclusively used for industrial buildings requiring high overhead lighting. Long runs of clerestory windows operated by mechanical tension rod gears were typical. Long banks of continuous windows were possible because the frames for such windows were often structural elements of the building.</p>

Fig. 4 Typical rolled steel windows available from 1890 to the present. The various operating and ventilating capacities in combination with the aesthetics of the window style were important considerations in the selection of one window type over another. Drawings: Sharon C. Park, AIA.

If it is determined that the windows are in basically sound condition, the following steps can be taken: 1) removal of light rust, flaking and excessive paint; 2) priming of exposed metal with a rust-inhibiting primer; 3) replacement of cracked or broken glass and glazing compound; 4) replacement of missing screws or fasteners; 5) cleaning and lubrication of hinges; 6) repainting of all steel sections with two coats of finish paint compatible with the primer; and 7) caulking the masonry surrounds with a high quality elastomeric caulk.

Recommended methods for removing light rust include manual and mechanical abrasion or the application of chemicals. Burning off rust with an oxy-acetylene or propane torch, or an inert gas welding gun, should never be attempted because the heat can distort the metal. In addition, such intense heat (often as high as 3800° F) vaporizes the lead in old paint, resulting in highly toxic fumes. Furthermore, such heat will likely result in broken glass. Rust can best be removed using a wire brush, an aluminum oxide sandpaper, or a variety of power tools



Fig. 5 Windows often provide a strong visual element to relatively simple or unadorned industrial or commercial buildings. This design element should be taken into consideration when evaluating the significance of the windows. Photo: Michael Auer.

adapted for abrasive cleaning such as an electric drill with a wire brush or a rotary whip attachment. Adjacent sills and window jambs may need protective shielding.

Rust can also be removed from ferrous metals by using a number of commercially prepared anti-corrosive acid compounds. Effective on light and medium corrosion, these compounds can be purchased either as liquids or gels. Several bases are available, including phosphoric acid, ammonium citrate, oxalic acid and hydrochloric acid. Hydrochloric acid is generally not recommended; it can leave chloride deposits, which cause future corrosion. Phosphoric acid-based compounds do not leave such deposits, and are therefore safer for steel windows. However, any chemical residue should be wiped off with damp cloths, then dried immediately. Industrial blow-dryers work well for thorough drying. The use of running water to remove chemical residue is never recommended because the water may spread the chemicals to adjacent surfaces, and drying of these surfaces may be more difficult. Acid cleaning compounds will stain masonry; therefore plastic sheets should be taped to the edge of the metal sections to protect the masonry surrounds. The same measure should be followed to protect the glazing from etching because of acid contact.

Measures that remove rust will ordinarily remove flaking paint as well. Remaining loose or flaking paint can be removed with a chemical paint remover or with a pneumatic needle scaler or gun, which comes with a series of chisel blades and has proven effective in removing flaking paint from metal windows. Well-bonded paint may serve to protect the metal further from corrosion, and need not be removed unless paint build-up prevents the window from closing tightly. The edges should be feathered by sanding to give a good surface for repainting.

Next, any *bare* metal should be wiped with a cleaning solvent such as denatured alcohol, and dried immediately in preparation for the application of an anti-corrosive primer. Since corrosion can recur very soon after metal has been exposed to the air, the metal should be primed immediately after cleaning. Spot priming may be required periodically as other repairs are undertaken. Anti-corrosive primers generally consist of oil-alkyd based paints rich in zinc or zinc chromate.<sup>2</sup> Red lead is no longer available because of its toxicity. All metal primers, however, are toxic to some degree and should be handled carefully. Two coats of primer are recommended. Manufacturer's recommendations should be followed concerning application of primers.

## REPAIR

### Repair in Place

The maintenance procedures described above will be insufficient when corrosion is extensive, or when metal window sections are misaligned. Medium to heavy corrosion that has not done any structural damage to the metal sections can be removed either by using the chemical cleaning

process described under "Routine Maintenance" or by sandblasting. Since sandblasting can damage the masonry surrounds and crack or cloud the glass, metal or plywood shields should be used to protect these materials. The sandblasting pressure should be low, 80-100 pounds per square inch, and the grit size should be in the range of #10-#45. Glass peening beads (glass pellets) have also been successfully used in cleaning steel sections. While sandblasting equipment comes with various nozzle sizes, pencil-point blasters are most useful because they give the operator more effective control over the direction of the spray. The small aperture of the pencil-point blaster is also useful in removing dried putty from the metal sections that hold the glass. As with any cleaning technique, once the bare metal is exposed to air, it should be primed as soon as possible. This includes the inside rabbeted section of sash where glazing putty has been removed. To reduce the dust, some local codes allow only wet blasting. In this case, the metal must be dried immediately, generally with a blow-drier (a step that the owner should consider when calculating the time and expense involved). Either form of sandblasting metal covered with lead paints produces toxic dust. Proper precautionary measures should be taken against toxic dust and silica particles.

Bent or bowed metal sections may be the result of damage to the window through an impact or corrosive expansion. If the distortion is not too great, it is possible to realign the metal sections without removing the window to a metal fabricator's shop. The glazing is generally removed and pressure is applied to the bent or bowed section. In the case of a muntin, a protective 2 x 4 wooden bracing can be placed behind the bent portion and a wire cable with a winch can apply progressively more pressure over several days until the section is realigned. The 2 x 4 bracing is necessary to distribute the pressure evenly over the damaged section. Sometimes a section, such as the bottom of the frame, will bow out as a result of pressure exerted by corrosion and it is often necessary to cut the metal section to relieve this pressure prior to pressing the section back into shape and making a welded repair.

Once the metal sections have been cleaned of all corrosion and straightened, small holes and uneven areas resulting from rusting should be filled with a patching material and sanded smooth to eliminate pockets where water can accumulate. A patching material of steel fibers and an epoxy binder may be the easiest to apply. This steel-based epoxy is available for industrial steel repair; it can also be found in auto body patching compounds or in plumber's epoxy. As with any product, it is important to follow the manufacturer's instructions for proper use and best results. The traditional patching technique—melting steel welding rods to fill holes in the metal sections—may be difficult to apply in some situations; moreover, the window glass must be removed during the repair process, or it will crack from the expansion of the heated metal sections. After these repairs, glass replacement, hinge lubrication, painting, and other cosmetic repairs can be undertaken as necessary.

<sup>2</sup>Refer to Table IV. Types of Paint Used for Painting Metal in *Metals in America's Historic Buildings*, p. 139. (See bibliography).

To complete the checklist for routine maintenance, cracked glass, deteriorated glazing compound, missing screws, and broken fasteners will have to be replaced; hinges cleaned and lubricated; the metal windows painted, and the masonry surrounds caulked. If the glazing must be replaced, all clips, glazing beads, and other fasteners that hold the glass to the sash should be retained, if possible, although replacements for these parts are still being fabricated. When bedding glass, use only glazing compound formulated for metal windows. To clean the hinges (generally brass or bronze), a cleaning solvent and fine bronze wool should be used. The hinges should then be lubricated with a non-greasy lubricant specially formulated for metals and with an anti-corrosive agent. These lubricants are available in a spray form and should be used periodically on frequently opened windows.

Final painting of the windows with a paint compatible with the anti-corrosive primer should proceed on a dry day. (Paint and primer from the same manufacturer should be used.) Two coats of finish paint are recommended if the sections have been cleaned to bare metal. The paint should overlap the glass slightly to insure weathertightness at that connection. Once the paint dries thoroughly, a flexible exterior caulk can be applied to eliminate air and moisture infiltration where the window and the surrounding masonry meet.

Caulking is generally undertaken after the windows have received at least one coat of finish paint. The perimeter of the masonry surround should be caulked with a flexible elastomeric compound that will adhere well to both metal and masonry. The caulking used should be a type intended for exterior application, have a high tolerance for material movement, be resistant to ultraviolet light, and have a minimum durability of 10 years. Three effective compounds (taking price and other factors into consideration) are polyurethane, vinyl acrylic, and butyl rubber. In selecting a caulking material for a window retrofit, it is important to remember that the caulking compound may be covering other materials in a substrate. In this case, some compounds, such as silicone, may not adhere well. Almost all modern caulking compounds can be painted after curing completely. Many come in a range of colors, which eliminates the need to paint. If colored caulking is used, the windows should have been given two coats of finish paint prior to caulking.

### Repair in Workshop

Damage to windows may be so severe that the window sash and sometimes the frame must be removed for cleaning and extensive rust removal, straightening of bent sections, welding or splicing in of new sections, and reglazing. These major and expensive repairs are reserved for highly significant windows that cannot be replaced; the procedures involved should be carried out only by skilled workmen. (see fig. 6a—6f.)

As part of the orderly removal of windows, each window should be numbered and the parts labelled. The operable metal sash should be dismantled by removing the hinges; the fixed sash and, if necessary, the frame can then be unbolted or unscrewed. (The subframe is usually left in place. Built into the masonry surrounds, it can only be cut out with a torch.) Hardware and hinges should be labelled and stored together.

The two major choices for removing flaking paint and corrosion from severely deteriorated windows are dipping in a chemical bath or sandblasting. Both treatments require removal of the glass. If the windows are to be dipped, a phosphoric acid solution is preferred, as mentioned earlier. While the dip tank method is good for fairly evenly distributed rust, deep set rust may remain after dipping. For that reason, sandblasting is more effective for heavy and uneven corrosion. Both methods leave the metal sections clean of residual paint. As already noted, after cleaning has exposed the metal to the air, it should be primed immediately after drying with an anti-corrosive primer to prevent rust from recurring.

Sections that are seriously bent or bowed must be straightened with heat and applied pressure in a workshop. Structurally weakened sections must be cut out, generally with an oxy-acetylene torch, and replaced with sections welded in place and the welds ground smooth. Finding replacement metal sections, however, may be difficult. While most rolling mills are producing modern sections suitable for total replacement, it may be difficult to find an exact profile match for a splicing repair. The best source of rolled metal sections is from salvaged windows, preferably from the same building. If no salvaged windows are available, two options remain. Either an ornamental metal fabricator can weld flat plates into a built-up section, or a steel plant can mill bar steel into the desired profile.

While the sash and frame are removed for repair, the subframe and masonry surrounds should be inspected. This is also the time to reset sills or to remove corrosion from the subframe, taking care to protect the masonry surrounds from damage.

Missing or broken hardware and hinges should be replaced on all windows that will be operable. Salvaged windows, again, are the best source of replacement parts. If matching parts cannot be found, it may be possible to adapt ready-made items. Such a substitution may require filling existing holes with steel epoxy or with plug welds and tapping in new screw holes. However, if the hardware is a highly significant element of the historic window, it may be worth having reproductions made.

Following are illustrations of the repair and thermal upgrading of the rolled steel windows in a National Historic Landmark (fig. 6). Many of the techniques described above were used during this extensive rehabilitation. The complete range of repair techniques is then summarized in the chart titled *Steps for Cleaning and Repairing Historic Steel Windows* (see fig. 7).

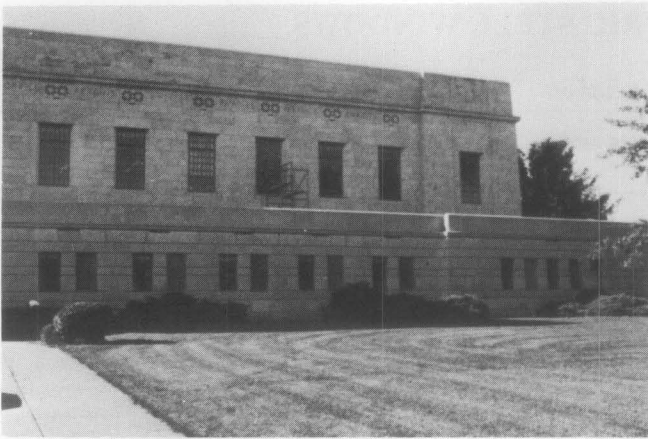


Fig. 6 a. View of the flanking wing of the State Capitol where the rolled steel casement windows are being removed for repair.

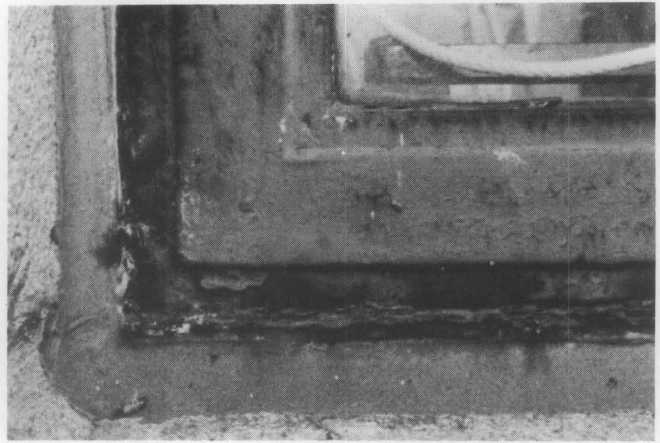


Fig. 6 b. View from the exterior showing the deteriorated condition of the lower corner of a window prior to repair. While the sash was in relatively good condition, the frame behind was rusted to the point of inhibiting operation.

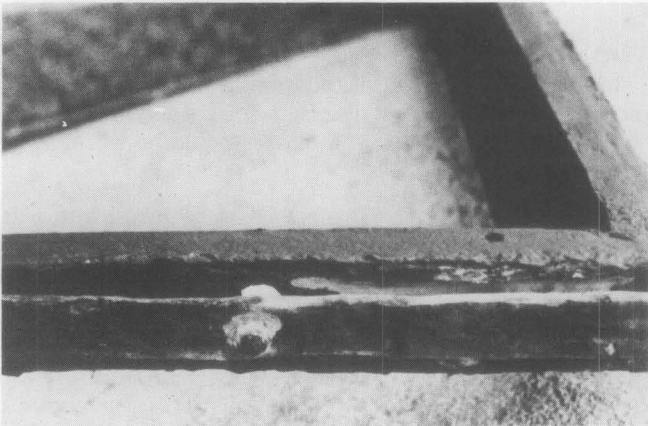


Fig. 6 c. View of the rusted frame which was unscrewed from the subframe and removed from the window opening and taken to a workshop for sandblasting. In some cases, severely deteriorated sections of the frame were replaced with new sections of milled bar steel.



Fig. 6 d. View looking down towards the sill. The subframes appeared very rusted, but were in good condition once debris was vacuumed and surface rust was removed, in place, with chemical compounds. Where necessary, epoxy and steel filler was used to patch depressions in order to make the subframe serviceable again.

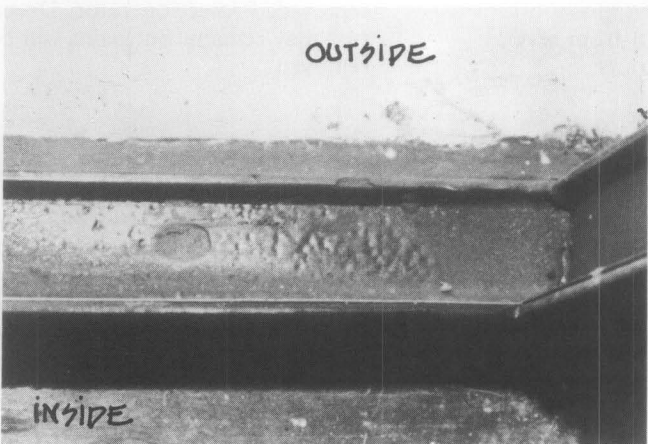


Fig. 6 e. View looking down towards the sill. The cleaned frame was reset in the window opening. The frame was screwed to the refurbished subframe at the jamb and the head only. The screw holes at the sill, which had been the cause of much of the earlier rusting, were infilled. Vinyl weatherstripping was added to the frame.

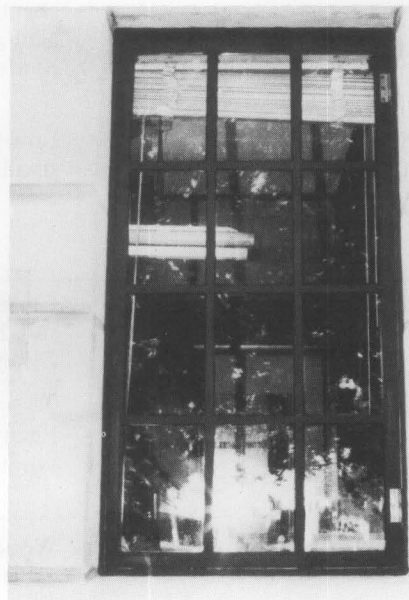


Fig. 6 f. View from the outside of the completely refurbished window. In addition to the steel repair and the installation of vinyl weatherstripping, the exterior was caulked with polyurethane and the single glass was replaced with individual lights of thermal glass. The repaired and upgraded windows have comparable energy efficiency ratings to new replacement units while retaining the historic steel sash, frames and subframes.

Fig. 6. The repair and thermal upgrading of the historic steel windows at the State Capitol, Lincoln, Nebraska. This early twentieth century building, designed by Bertram Goodhue, is a National Historic Landmark. Photos: All photos in this series were provided by the State Building Division.

## STEPS FOR CLEANING AND REPAIRING HISTORIC STEEL WINDOWS

Work Item	Recommended Techniques	Tools, Products and Procedures	Notes
	*(Must be done in a workshop)		
1. Removing dirt and grease from metal	General maintenance and chemical cleaning	Vacuum and bristle brushes to remove dust and dirt; solvents (denatured alcohol, mineral spirits), and clean cloths to remove grease.	Solvents can cause eye and skin irritation. Operator should wear protective gear and work in ventilated area. Solvents should not contact masonry. Do not flush with water.
2. Removing Rust/Corrosion			
Light	Manual and mechanical abrasion	Wire brushes, steel wool, rotary attachments to electric drill, sanding blocks and disks.	Hand sanding will probably be necessary for corners. Safety goggles and masks should be worn.
	Chemical cleaning	Anti-corrosive jellies and liquids (phosphoric acid preferred); clean damp cloths.	Protect glass and metal with plastic sheets attached with tape. Do not flush with water. Work in ventilated area.
Medium	Sandblasting/abrasive cleaning	Low pressure (80-100 psi) and small grit (#10-#45); glass peening beads. Pencil blaster gives good control.	Removes both paint and rust. Codes should be checked for environmental compliance. Prime exposed metal promptly. Shield glass and masonry. Operator should wear safety gear.
Heavy	*Chemical dip tank	Metal sections dipped into chemical tank (phosphoric acid preferred) from several hours to 24 hours.	Glass and hardware should be removed. Protect operator. Deepset rust may remain, but paint will be removed.
	*Sandblasting/abrasive cleaning	Low pressure (80-100 psi) and small grit (#10-#45).	Excellent for heavy rust. Remove or protect glass. Prime exposed metal promptly. Check codes for environmental compliance. Operator should wear safety gear.
3. Removing flaking paint.	Chemical method	Chemical paint strippers suitable for ferrous metals. Clean cloths.	Protect glass and masonry. Do not flush with water. Have good ventilation and protection for operator.
	Mechanical abrasion	Pneumatic needle gun chisels, sanding disks.	Protect operator; have good ventilation. Well-bonded paint need not be removed if window closes properly.
4. Aligning bent, bowed metal sections	Applied pressure	Wooden frame as a brace for cables and winch mechanism.	Remove glass in affected area. Realignment may take several days.
	*Heat and pressure	Remove to a workshop. Apply heat and pressure to bend back.	Care should be taken that heat does not deform slender sections.



Work Item	Recommended Techniques	Tools, Products and Procedures	Notes
	*(Must be done in a workshop)		
5. Patching depressions	Epoxy and steel filler	Epoxy fillers with high content of steel fibers; plumber's epoxy or autobody patching compound.	Epoxy patches generally are easy to apply, and can be sanded smooth. Patches should be primed.
	Welded patches	Weld in patches using steel rods and oxy-acetylene torch or arc welder.	Prime welded sections after grinding connections smooth.
6. Splicing in new metal sections	*Cut out decayed sections and weld in new or salvaged sections	Torch to cut out bad sections back to 45° joint. Weld in new pieces and grind smooth.	Prime welded sections after grinding connection smooth.
7. Priming metal sections	Brush or spray application	At least one coat of anti-corrosive primer on bare metal. Zinc-rich primers are generally recommended.	Metal should be primed as soon as it is exposed. If cleaned metal will be repaired another day, spot prime to protect exposed metal.
8. Replacing missing screws and bolts	Routine maintenance	Pliers to pull out or shear off rusted heads. Replace screws and bolts with similar ones, readily available.	If new holes have to be tapped into the metal sections, the rusted holes should be cleaned, filled and primed prior to redrilling.
9. Cleaning, lubricating or replacing hinges and other hardware	Routine maintenance, solvent cleaning	Most hinges and closure hardware are bronze. Use solvents (mineral spirits), bronze wool and clean cloths. Spray with non-greasy lubricant containing anti-corrosive agent.	Replacement hinges and fasteners may not match the original exactly. If new holes are necessary, old ones should be filled.
10. Replacing glass and glazing compound	Standard method for application	Pliers and chisels to remove old glass, scrape putty out of glazing rabbet, save all clips and beads for reuse. Use only glazing compound formulated for metal windows.	Heavy gloves and other protective gear needed for the operator. All parts saved should be cleaned prior to reinstallation.
11. Caulking masonry surrounds	Standard method for application	Good quality (10 year or better) elastomeric caulking compound suitable for metal.	The gap between the metal frame and the masonry opening should be caulked; keep weepholes in metal for condensation run-off clear of caulk.
12. Repainting metal windows	Spray or brush	At least 2 coats of paint compatible with the anti-corrosive primer. Paint should lap the glass about 1/8" to form a seal over the glazing compound.	The final coats of paint and the primer should be from the same manufacturer to ensure compatibility. If spraying is used, the glass and masonry should be protected.

Fig. 7. STEPS FOR CLEANING AND REPAIRING HISTORIC STEEL WINDOWS. Compiled by Sharon C. Park, AIA.

## WEATHERIZATION

Historic metal windows are generally not energy efficient; this has often led to their wholesale replacement. Metal windows can, however, be made more energy efficient in several ways, varying in complexity and cost. Caulking around the masonry openings and adding weatherstripping, for example, can be do-it-yourself projects and are important first steps in reducing air infiltration around the windows. They usually have a rapid payback period. Other treatments include applying fixed layers of glazing over the historic windows, adding operable storm windows, or installing thermal glass in place of the existing glass. In combination with caulking and weatherstripping, these treatments can produce energy ratings rivaling those achieved by new units.<sup>3</sup>

### Weatherstripping

The first step in any weatherization program, caulking, has been discussed above under "Routine Maintenance." The second step is the installation of weatherstripping where the operable portion of the sash, often called the ventilator, and the fixed frame come together to reduce perimeter air infiltration (see fig. 8). Four types of weatherstripping appropriate for metal windows are spring-metal, vinyl strips, compressible foam tapes, and sealant beads. The spring-metal, with an integral friction fit mounting clip, is recommended for steel windows in good condition. The clip eliminates the need for an applied glue; the thinness of the material insures a tight closure. The weatherstripping is clipped to the inside channel of the rolled metal section of the fixed frame. To insure against galvanic corrosion between the weatherstripping (often bronze or brass), and the steel window, the window must be painted prior to the installation of the weatherstripping. This weatherstripping is usually applied to the entire perimeter of the window opening, but in some cases, such as casement windows, it may be best to avoid weatherstripping the hinge side. The natural wedging action of the weatherstripping on the three sides of the window often creates an adequate seal.

Vinyl weatherstripping can also be applied to metal windows. Folded into a "V" configuration, the material forms a barrier against the wind. Vinyl weatherstripping is usually glued to the frame, although some brands have an adhesive backing. As the vinyl material and the applied glue are relatively thick, this form of weatherstripping may not be appropriate for all situations.

Compressible foam tape weatherstripping is often best for large windows where there is a slight bending or distortion of the sash. In some very tall windows having closure hardware at the sash mid-point, the thin sections

of the metal window will bow away from the frame near the top. If the gap is not more than 1/4", foam weatherstripping can normally fill the space. If the gap exceeds this, the window may need to be realigned to close more tightly. The foam weatherstripping comes either with an adhesive or plain back; the latter variety requires application with glue. Compressible foam requires more frequent replacement than either spring-metal or vinyl weatherstripping.

A fourth type of successful weatherstripping involves the use of a caulking or sealant bead and a polyethylene bond breaker tape. After the window frame has been thoroughly cleaned with solvent, permitted to dry, and primed, a neat bead of low modulus (firm setting) caulk, such as silicone, is applied. A bond breaker tape is then applied to the operable sash covering the metal section where contact will occur. The window is then closed until the sealant has set (2-7 days, depending on temperature and humidity). When the window is opened, the bead will have taken the shape of the air infiltration gap and the bond breaker tape can be removed. This weatherstripping method appears to be successful for all types of metal windows with varying degrees of air infiltration.

Since the several types of weatherstripping are appropriate for different circumstances, it may be necessary to use more than one type on any given building. Successful weatherstripping depends upon using the thinnest material adequate to fill the space through which air enters. Weatherstripping that is too thick can spring the hinges, thereby resulting in more gaps.

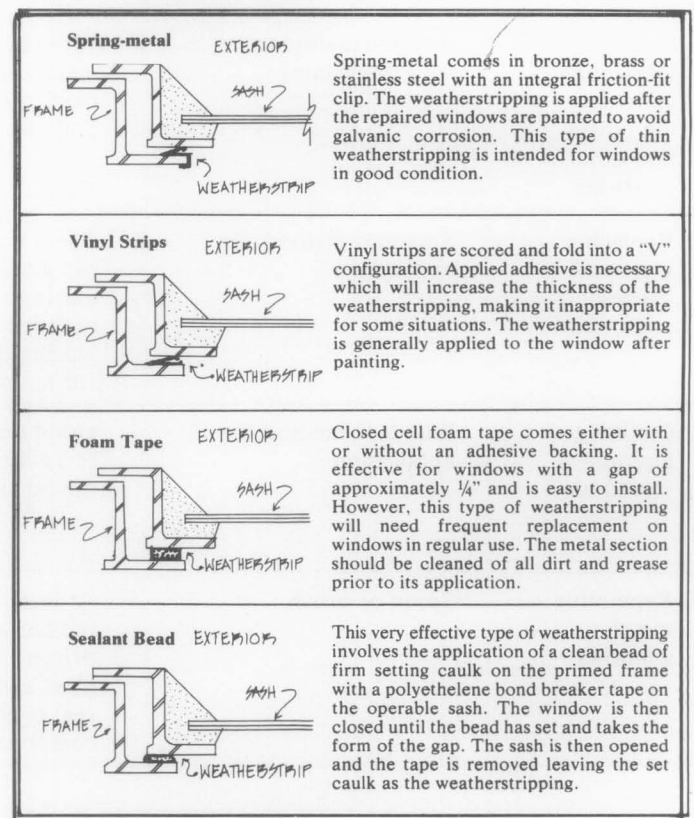


Fig. 8 APPROPRIATE TYPES OF WEATHERSTRIPPING FOR METAL WINDOWS. Weatherstripping is an important part of upgrading the thermal efficiency of historic steel windows. The chart above shows the jamb section of the window with the weatherstripping in place. Drawings: Sharon C. Park, AIA.

<sup>3</sup>One measure of energy efficiency is the U-value (the number of BTUs per hour transferred through a square foot of material). The lower the U-value, the better the performance. According to *ASHRAE HANDBOOK-1977 Fundamentals*, the U-value of historic rolled steel sash with single glazing is 1.3. Adding storm windows to the existing units or reglazing with 5/8" insulating glass produces a U-value of .69. These methods of weatherizing historic steel windows compare favorably with rolled steel replacement alternatives: with factory installed 1" insulating glass (.67 U-value); with added thermal-break construction and factory finish coatings (.62 U-value).

## Thermal Glazing

The third weatherization treatment is to install an additional layer of glazing to improve the thermal efficiency of the existing window. The decision to pursue this treatment should proceed from careful analysis. Each of the most common techniques for adding a layer of glazing will effect approximately the same energy savings (approximately double the original insulating value of the windows); therefore, cost and aesthetic considerations usually determine the choice of method. Methods of adding a layer of glazing to improve thermal efficiency include adding a new layer of transparent material to the window; adding a separate storm window; and replacing the single layer of glass in the window with thermal glass.

The least expensive of these options is to install a clear material (usually rigid sheets of acrylic or glass) over the original window. The choice between acrylic and glass is generally based on cost, ability of the window to support the material, and long-term maintenance outlook. If the material is placed over the entire window and secured to the frame, the sash will be inoperable. If the continued use of the window is important (for ventilation or for fire exits), separate panels should be affixed to the sash without obstructing operability (see fig. 9). Glass or acrylic panels set in frames can be attached using magnetized gaskets, interlocking material strips, screws or adhesives. Acrylic panels can be screwed directly to the metal windows, but the holes in the acrylic panels should allow for the expansion and contraction of this material. A compressible gasket between the prime sash and the storm panel can be very effective in establishing a thermal cavity between glazing layers. To avoid condensation, 1/8" cuts in a top corner and diagonally opposite bottom corner of the gasket will provide a vapor bleed, through which moisture can evaporate. (Such cuts, however, reduce thermal performance slightly.) If condensation does occur, however, the panels should be easily removable in order to wipe away moisture before it causes corrosion.

The second method of adding a layer of glazing is to have independent storm windows fabricated. (Pivot and austral windows, however, which project on either side of the window frame when open, cannot easily be fitted with storm windows and remain operational.) The storm window should be compatible with the original sash configuration. For example, in paired casement windows, either specially fabricated storm casement windows or sliding units in which the vertical meeting rail of the slider reflects the configuration of the original window should be installed. The decision to place storm windows on the inside or outside of the window depends on whether the historic window opens in or out, and on the visual impact the addition of storm windows will have on the building. Exterior storm windows, however, can serve another purpose besides saving energy: they add a layer of protection against air pollutants and vandals, although they will partially obscure the prime window. For highly ornamental windows this protection can determine the choice of exterior rather than interior storm windows.

The third method of installing an added layer of glazing is to replace the original single glazing with thermal glass. Except in rare instances in which the original glass is of special interest (as with stained or figured glass), the glass can be replaced if the hinges can tolerate the weight of the additional glass. The rolled metal sections for steel windows are generally from 1" - 1 1/2" thick. Sash of this thickness can normally tolerate thermal glass, which ranges from 3/8" - 5/8". (Metal glazing beads, readily available, are used to reinforce the muntins, which hold the glass.) This treatment leaves the window fully operational while preserving the historic appearance. It is, however, the most expensive of the treatments discussed here. (See fig. 6f).

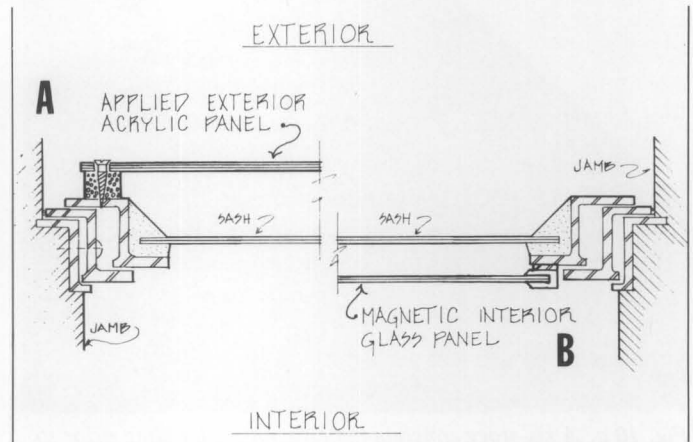


Fig. 9 Two examples of adding a second layer of glazing in order to improve the thermal performance of historic steel windows. Scheme A (showing jamb detail) is of a 1/4" acrylic panel with a closed cell foam gasket attached with self-tapping stainless steel screws directly to the exterior of the outwardly opening sash. Scheme B (showing jamb detail) is of a glass panel in a magnetized frame affixed directly to the interior of the historic steel sash. The choice of using glass or acrylic mounted on the inside or outside will depend on the ability of the window to tolerate additional weight, the location and size of the window, the cost, and the long-term maintenance outlook. Drawing: Sharon C. Park, AIA.

## WINDOW REPLACEMENT

Repair of historic windows is always preferred within a rehabilitation project. Replacement should be considered only as a last resort. However, when the extent of deterioration or the unavailability of replacement sections renders repair impossible, replacement of the entire window may be justified. In the case of significant windows, replacement in kind is essential in order to maintain the historic character of the building. However, for less significant windows, replacement with compatible new windows may be acceptable. In selecting compatible replacement windows, the material, configuration, color, operability, number and size of panes, profile and proportion of metal sections, and reflective quality of the original glass should be duplicated as closely as possible.

A number of metal window manufacturing companies produce rolled steel windows. While stock modern window designs do not share the multi-pane configuration of

historic windows, most of these manufacturers can reproduce the historic configuration if requested, and the cost is not excessive for large orders (see figs. 10a and 10b). Some manufacturers still carry the standard pre-World War II multi-light windows using the traditional 12" x 18" or 14" x 20" glass sizes in industrial, commercial, security, and residential configurations. In addition, many of the modern steel windows have integral weatherstripping, thermal break construction, durable vinyl coatings, insulating glass, and other desirable features.

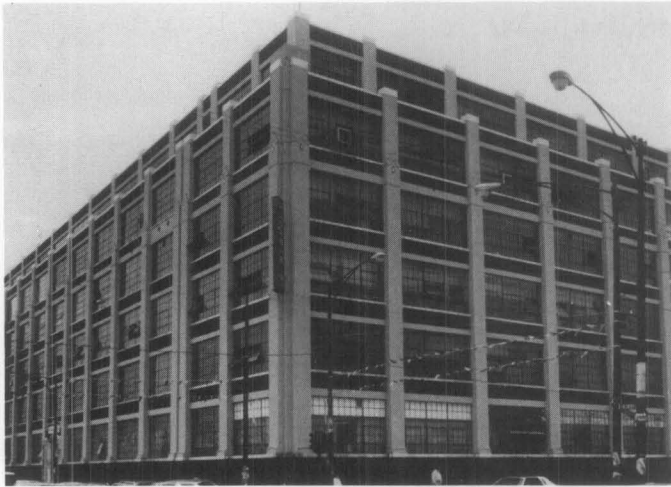


Fig. 10 a. A six-story concrete manufacturing building prior to the replacement of the steel pivot windows. Photo: Charles Parrott.



Fig. 10 b. Close-up view of the new replacement steel windows which matched the multi-lighted originals exactly. Photo: Charles Parrott.

Windows manufactured from other materials generally cannot match the thin profiles of the rolled steel sections. Aluminum, for example, is three times weaker than steel and must be extruded into a box-like configuration that does not reflect the thin historic profiles of most steel windows. Wooden and vinyl replacement windows generally are not fabricated in the industrial style, nor can they reproduce the thin profiles of the rolled steel sections, and consequently are generally not acceptable replacements.

For product information on replacement windows, the owner, architect, or contractor should consult manufacturers' catalogues, building trade journals, or the Steel Window Institute, 1230 Keith Building, Cleveland, Ohio 44115.

## SUMMARY

The National Park Service recommends the retention of significant historic metal windows whenever possible. Such windows, which can be a character-defining feature of a historic building, are too often replaced with inappropriate units that impair rather than complement the overall historic appearance. The repair and thermal upgrading of historic steel windows is more practicable than most people realize. Repaired and properly maintained metal windows have greatly extended service lives. They can be made energy efficient while maintaining their contribution to the historic character of the building.

## BIBLIOGRAPHY

- ASHRAE Handbook - 1977 Fundamentals*. New York: American Society of Heating, Refrigerating and Airconditioning Engineers, 1978.
- Crittall, W. F. *A Metal Window Dictionary*. London: Curwen Press, 1926. Reprinted by B.T. Batsford, Ltd., 1953.
- Gayle, Margot; David W. Look, AIA; John G. Waite. *Metals in America's Historic Buildings: Uses and Preservation Treatments*. Technical Preservation Services, U.S. Department of the Interior, Washington, D.C.: U.S. Government Printing Office, 1980.
- Gillet, William. "Steel Windows." *Windows and Glass in the Exterior of Buildings*. National Academy of Sciences Publication 478. Washington, D.C.: 1957, 75-78.
- Sarton, R. H. "Selecting and Specifying an Appropriate Type of Steel Window." *Metalcraft*. Vol 6, No. 1 (January, 1931): 43-48, 64-65.
- Sweet's Architectural Catalogue*. 13th Edition, New York, Sweets Catalogue Service, Inc., 1918.

The author gratefully acknowledges the invaluable assistance of co-worker Michael Auer in preparing this brief for publication. This publication is an extension of research initiated by Frederec E. Kleye. Special thanks are given to Hope's Architectural Products, Inc., Jamestown, NY, for their generous contribution of historic metal window catalogues which were an invaluable source of information. The following individuals are also to be thanked for reviewing the manuscript and making suggestions: Hugh Miller, Chief, Park Historic Architecture Division, National Park Service; Barclay L. Rogers, Museum Services, National Park Service; Susan M. Young, Steel Window Institute, and Danny Schlichenmaier, State Building Division, Lincoln, Nebraska. Finally, thanks go to Technical Preservation Services Branch staff and to cultural resources staff of the National Park Service Regional Offices, whose valuable comments were incorporated into the final text and who contributed to the publication of this brief.

This publication has been prepared pursuant to the Economic Recovery Tax Act of 1981, which directs the Secretary of the Interior to certify rehabilitations of historic buildings that are consistent with their historic character; the guidance provided in this brief will assist property owners in complying with the requirements of this law.

*Preservation Briefs: 13* has been developed under the technical editorship of Lee H. Nelson, AIA, Chief, Preservation Assistance Division, National Park Service, U.S. Department of the Interior, Washington, D.C. 20240. Comments on the usefulness of this information are welcomed and can be sent to Mr. Nelson at the above address.

# 14 PRESERVATION BRIEFS

## New Exterior Additions to Historic Buildings: Preservation Concerns

Anne E. Grimmer and Kay D. Weeks



National Park Service  
U.S. Department of the Interior  
Technical Preservation Services



A new exterior addition to a historic building should be considered in a rehabilitation project only after determining that requirements for the new or adaptive use cannot be successfully met by altering non-significant interior spaces. If the new use cannot be accommodated in this way, then an exterior addition may be an acceptable alternative. Rehabilitation as a treatment “is defined as the act or process of making possible a compatible use for a property through repair, alterations, and *additions* while preserving those portions or features which convey its historical, cultural, or architectural values.”

The topic of new additions, including rooftop additions, to historic buildings comes up frequently, especially as it

relates to rehabilitation projects. It is often discussed and it is the subject of concern, consternation, considerable disagreement and confusion. Can, in certain instances, a historic building be enlarged for a new use without destroying its historic character? And, just what is significant about each particular historic building that should be preserved? Finally, what kind of new construction is appropriate to the historic building?

The vast amount of literature on the subject of additions to historic buildings reflects widespread interest as well as divergence of opinion. New additions have been discussed by historians within a social and political framework; by architects and architectural historians in terms of construction technology and style; and

by urban planners as successful or unsuccessful contextual design. However, within the historic preservation and rehabilitation programs of the National Park Service, the focus on new additions is to ensure that they preserve the character of historic buildings.

Most historic districts or neighborhoods are listed in the National Register of Historic Places for their significance within a particular time frame. This period of significance of historic districts as well as individually-listed properties may sometimes lead to a misunderstanding that inclusion in the National Register may prohibit any physical change outside of a certain historical period — particularly in the form of exterior additions. National Register listing does not mean that a building or district is frozen in time and that no change can be made without compromising the historical significance. It does mean, however, that a new addition to a historic building should preserve its historic character.



Figure 1. The addition to the right with its connecting hyphen is compatible with the Collegiate Gothic-style library. The addition is set back from the front of the library and uses the same materials and a simplified design that references, but does not copy, the historic building. Photo: David Wakely Photography.



Figure 2. The new section on the right is appropriately scaled and reflects the design of the historic Art Deco-style hotel. The apparent separation created by the recessed connector also enables the addition to be viewed as an individual building.

## Guidance on New Additions

To meet Standard 1 of the *Secretary of the Interior's Standards for Rehabilitation*, which states that "a property shall be used for its historic purpose or be placed in a new use that requires minimal change to the defining characteristics of the building and its site and environment," it must be determined whether a historic building can accommodate a new addition. Before expanding the building's footprint, consideration should first be given to incorporating changes—such as code upgrades or spatial needs for a new use—within secondary areas of the historic building. However, this is not always possible and, after such an evaluation, the conclusion may be that an addition is required, particularly if it is needed to avoid modifications to character-defining interior spaces. An addition should be designed to be compatible with the historic character of the building and, thus, meet the *Standards for Rehabilitation*. Standards 9 and 10 apply specifically to new additions:

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

(10) "New additions and adjacent or related new construction shall be undertaken in such a manner that if removed in the future, the essential form and integrity of the historic property and its environment would be unimpaired."

The subject of new additions is important because a new addition to a historic building has the potential to change its historic character as well as to damage and destroy significant historic materials and features. A new addition also has the potential to confuse the public and to make it difficult or impossible to differentiate the old from the new or to recognize what part of the historic building is genuinely historic.

The intent of this Preservation Brief is to provide guidance to owners, architects and developers on how to design a compatible new addition, including a rooftop addition, to a historic building. A new addition to a historic building should preserve the building's *historic character*. To accomplish this and meet the *Secretary of the Interior's Standards for Rehabilitation*, a new addition should:

- Preserve significant historic materials, features and form;
- Be compatible; and
- Be differentiated from the historic building.

Every historic building is different and each rehabilitation project is unique. Therefore, the guidance offered here is not specific, but general, so that it can be applied to a wide variety of building types and situations. To assist in interpreting this guidance, illustrations of a variety of new additions are provided. Good examples, as well as some that do not meet the Standards, are included to further help explain and clarify what is a compatible new addition that preserves the character of the historic building.



Figure 3. The red and buff-colored parking addition with a rooftop playground is compatible with the early-20th century school as well as with the neighborhood in which it also serves as infill in the urban setting.

## *Preserve Significant Historic Materials, Features and Form*

Attaching a new exterior addition usually involves some degree of material loss to an external wall of a historic building, but it should be minimized. Damaging or destroying significant materials and craftsmanship should be avoided, as much as possible.

Generally speaking, preservation of historic buildings inherently implies minimal change to primary or “public” elevations and, of course, interior features as well. Exterior features that distinguish one historic building or a row of buildings and which can be seen from a public right of way, such as a street or sidewalk, are most likely to be the most significant. These can include many different elements, such as: window patterns, window hoods or shutters; porticoes, entrances and doorways; roof shapes, cornices and decorative moldings; or commercial storefronts with their special detailing, signs and glazing patterns. Beyond a single building, entire blocks of urban or residential structures are often closely related architecturally by their materials, detailing, form and alignment. Because significant materials and features should be preserved, not damaged or hidden, the first place to consider placing a new addition is in a location where the least amount of historic material and character-defining features will be lost. In most cases, this will be on a secondary side or rear elevation.

One way to reduce overall material loss when constructing a new addition is simply to keep the addition smaller in proportion to the size of the historic building. Limiting the size and number of openings between old and new by utilizing existing doors or enlarging windows also helps to minimize loss. An often successful way to accomplish this is to link the addition to the historic building by means of a hyphen or connector. A connector provides a physical link while visually separating the old and new, and the connecting passageway penetrates and removes only a small portion of the historic wall. A new addition that will abut the historic building along an entire elevation or wrap around a side and rear elevation, will likely integrate the historic and the new interiors, and thus result in a high degree of loss of form and exterior walls, as well as significant alteration of interior spaces and features, and will not meet the Standards.



*Figure 4. This glass and brick structure is a harmonious addition set back and connected to the rear of the Colonial Revival-style brick house. Cunningham/Quill Architects. Photos: © Maxwell MacKenzie.*

## *Compatible but Differentiated Design*

In accordance with the Standards, a new addition must preserve the building’s historic character and, in order to do that, it must be differentiated, but compatible, with the historic building. A new addition must retain the essential form and integrity of the historic property. Keeping the addition smaller, limiting the removal of historic materials by linking the addition with a hyphen, and locating the new addition at the rear or on an inconspicuous side elevation of a historic building are techniques discussed previously that can help to accomplish this.

Rather than differentiating between old and new, it might seem more in keeping with the historic character

simply to repeat the historic form, material, features and detailing in a new addition. However, when the new work is highly replicative and indistinguishable from the old in appearance, it may no longer be possible to identify the “real” historic building. Conversely, the treatment of the addition should not be so different that it becomes the primary focus. The difference may be subtle, but it must be clear. A new addition to a historic building should protect those visual qualities that make the building eligible for listing in the National Register of Historic Places.

The National Park Service policy concerning new additions to historic buildings, which was adopted in 1967, is not unique. It is an outgrowth and continuation of a general philosophical approach to change first expressed by John Ruskin in England in the 1850s, formalized by William Morris in the founding of the Society for the Protection of Ancient Buildings in 1877, expanded by the Society in 1924 and, finally, reiterated in the 1964 Venice Charter—a document that continues to be followed by the national committees of the International Council on Monuments and Sites (ICOMOS). The 1967 *Administrative Policies for Historical Areas of the National Park System* direct that “...a modern addition should be readily distinguishable from the older work; however, the new work should be harmonious with the old in scale, proportion, materials, and color. Such additions should be as inconspicuous as

possible from the public view.” As a logical evolution from these Policies specifically for National Park Service-owned historic structures, the 1977 *Secretary of the Interior’s Standards for Rehabilitation*, which may be applied to **all** historic buildings listed in, or eligible for listing in the National Register, also state that “the new work shall be differentiated from the old and shall be compatible with the massing, size, scale, and architectural features to protect the historic integrity of the property and its environment.”

### *Preserve Historic Character*

The goal, of course, is a new addition that preserves the building’s historic character. The historic character of each building may be different, but the methodology of establishing it remains the same. Knowing the uses and functions a building has served over time will assist in making what is essentially a physical evaluation. But, while written and pictorial documentation can provide a framework for establishing the building’s history, to a large extent the historic character is embodied in the physical aspects of the historic building itself—shape, materials, features, craftsmanship, window arrangements, colors, setting and interiors. Thus, it is important to identify the historic character before making decisions about the extent—or limitations—of change that can be made.



Figure 5. This addition (a) is constructed of matching brick and attached by a recessed connector (b) to the 1914 apartment building (c). The design is compatible and the addition is smaller and subordinate to the historic building (d).





Figure 6. A new addition (left) is connected to the garage which separates it from the main block of the c. 1910 former florist shop (right). The addition is traditional in style, yet sufficiently restrained in design to distinguish it from the historic building.

A new addition should always be subordinate to the historic building; it should not compete in size, scale or design with the historic building. An addition that bears no relationship to the proportions and massing of the historic building—in other words, one that overpowers the historic form and changes the scale—will usually compromise the historic character as well. The appropriate size for a new addition varies from building to building; it could never be stated in a square or cubic footage ratio, but the historic building's existing proportions, site and setting can help set some general parameters for enlargement. Although even a small addition that is poorly designed can have an adverse impact, to some extent, there is a predictable relationship between the size of the historic resource and what is an appropriate size for a compatible new addition.

Generally, constructing the new addition on a secondary side or rear elevation—in addition to material preservation—will also preserve the historic character. Not only will the addition be less visible, but because a secondary elevation is usually simpler and less distinctive, the addition will have less of a physical and visual impact on the historic building. Such placement will help to preserve the building's historic form and relationship to its site and setting.

Historic landscape features, including distinctive grade variations, also need to be respected. Any new landscape features, including plants and trees, should be kept at a scale and density that will not interfere with understanding of the historic resource itself. A traditionally landscaped

property should not be covered with large paved areas for parking which would drastically change the character of the site.

Despite the fact that in most cases it is recommended that the new addition be attached to a secondary elevation, sometimes this is not possible. There simply may not be a secondary elevation—some important freestanding buildings have significant materials and features on all sides. A structure or group of structures together with its setting (for example, a college campus) may be of such significance that any new addition would not only damage materials, but alter the buildings' relationship to each other and the setting. An addition attached to a highly-visible elevation of a historic building can radically alter the historic form or obscure features such as a decorative cornice or window ornamentation. Similarly, an addition that fills



Figure 7. A vacant side lot was the only place a new stair tower could be built when this 1903 theater was rehabilitated as a performing arts center. Constructed with matching materials, the stair tower is set back with a recessed connector and, despite its prominent location, it is clearly subordinate and differentiated from the historic theater.

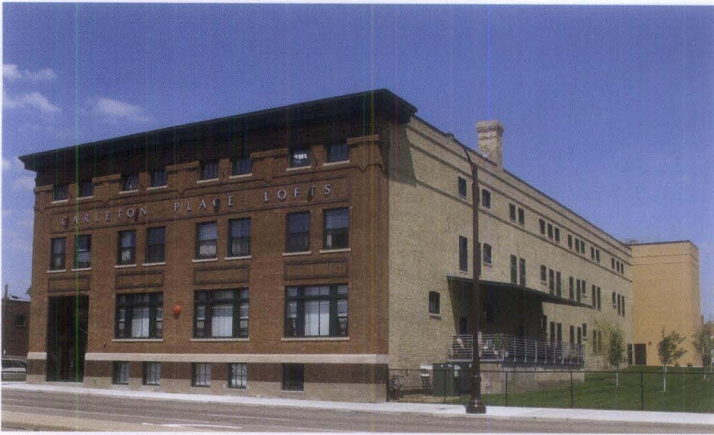


Figure 8. The rehabilitation of this large, early-20th century warehouse (left) into affordable artists' lofts included the addition of a compatible glass and brick elevator/stair tower at the back (right).



Figure 9. A simple, brick stair tower replaced two non-historic additions at the rear of this 1879 school building when it was rehabilitated as a women's and children's shelter. The addition is set back and it is not visible from the front of the school.



Figure 10. The small size and the use of matching materials ensures that the new addition on the left is compatible with the historic Romanesque Revival-style building.

in a planned void on a highly-visible elevation (such as a U-shaped plan or a feature such as a porch) will also alter the historic form and, as a result, change the historic character. Under these circumstances, an addition would have too much of a negative impact on the historic building and it would not meet the Standards. Such situations may best be handled by constructing a separate building in a location where it will not adversely affect the historic structure and its setting.

In other instances, particularly in urban areas, there may be no other place but adjacent to the primary façade to locate an addition needed for the new use. It may be possible to design a lateral addition attached on the side that is compatible with the historic building, even though it is a highly-visible new element. Certain types of historic structures, such as government buildings, metropolitan museums, churches or libraries, may be so massive in size that a relatively large-scale addition may not compromise the historic character, provided, of course, the addition is smaller than the historic building. Occasionally, the visible size of an addition can be reduced by placing some of the spaces or support systems in a part of the structure that is underground. Large new additions may sometimes be successful if they read as a separate volume, rather than as an extension of the historic structure, although the scale, massing and proportions of the addition still need to be compatible with the historic building. However, similar expansion of smaller buildings would be dramatically out of scale. In summary, where any new addition is proposed, correctly assessing the relationship between actual size and relative scale will be a key to preserving the character of the historic building.



Figure 11. The addition to this early-20th century Gothic Revival-style church provides space for offices, a great hall for gatherings and an accessible entrance (left). The stucco finish, metal roof, narrow gables and the Gothic-arched entrance complement the architecture of the historic church. Placing the addition in back where the ground slopes away ensures that it is subordinate and minimizes its impact on the church (below).

## Design Guidance for Compatible New Additions to Historic Buildings

There is no formula or prescription for designing a new addition that meets the Standards. A new addition to a historic building that meets the Standards can be any architectural style—traditional, contemporary or a simplified version of the historic building. However, there must be a balance between differentiation and compatibility in order to maintain the historic character and the identity of the building being enlarged. New additions that too closely resemble the historic building or are in extreme contrast to it fall short of this balance. *Inherent in all of the guidance is the concept that an addition needs to be subordinate to the historic building.*

A new addition **must preserve significant historic materials, features and form, and it must be compatible but differentiated from the historic building.** To achieve this, it is necessary to carefully consider the **placement or location** of the new addition, and its **size, scale and massing** when planning a new addition. To preserve a property's historic character, a new addition must be visually distinguishable from the historic building. This does not mean that the addition and the historic building should be glaringly different in terms of design, materials and other visual qualities. Instead, the new addition should take its design cues from, but not copy, the historic building.



A variety of design techniques can be effective ways to differentiate the new construction from the old, while respecting the architectural qualities and vocabulary of the historic building, including the following:

- Incorporate a simple, recessed, small-scale hyphen to physically separate the old and the new volumes or set the addition back from the wall plane(s) of the historic building.
- Avoid designs that unify the two volumes into a single architectural whole. The new addition may include simplified architectural features that reflect, but do not duplicate, similar features on the historic building. This approach will not impair the existing building's historic character as long as the new structure is subordinate in size and clearly differentiated and distinguishable so that the identity of the historic structure is not lost in a new and larger composition. The historic building must be clearly identifiable and its physical integrity must not be compromised by the new addition.



Figure 12. This 1954 synagogue (left) is accessed through a monumental entrance to the right. The new education wing (far right) added to it features the same vertical elements and color and, even though it is quite large, its smaller scale and height ensure that it is secondary to the historic resource.



Figure 13. A glass and metal structure was constructed in the courtyard as a restaurant when this 1839 building was converted to a hotel. Although such an addition might not be appropriate in a more public location, it is compatible here in the courtyard of this historic building.



Figure 14. This glass addition was erected at the back of an 1895 former brewery during rehabilitation to provide another entrance. The addition is compatible with the plain character of this secondary elevation.

- Use building materials in the same color range or value as those of the historic building. The materials need not be the same as those on the historic building, but they should be harmonious; they should not be so different that they stand out or distract from the historic building. (Even clear glass can be as prominent as a less transparent material. Generally, glass may be most appropriate for small-scale additions, such as an entrance on a secondary elevation or a connector between an addition and the historic building.)
- Base the size, rhythm and alignment of the new addition's window and door openings on those of the historic building.
- Respect the architectural expression of the historic building type. For example, an addition to an institutional building should maintain the architectural character associated with this building type rather than using details and elements typical of residential or other building types.

These techniques are merely examples of ways to differentiate a new addition from the historic building while ensuring that the addition is compatible with it. Other ways of differentiating a new addition from the historic building may be used as long as they maintain the primacy of the historic building. Working within these basic principles still allows for a broad range of architectural expression that can range from stylistic similarity to contemporary distinction. The recommended design approach for an addition is one that neither copies the historic building exactly nor stands in stark contrast to it.

## Revising an Incompatible Design for a New Addition to Meet the Standards

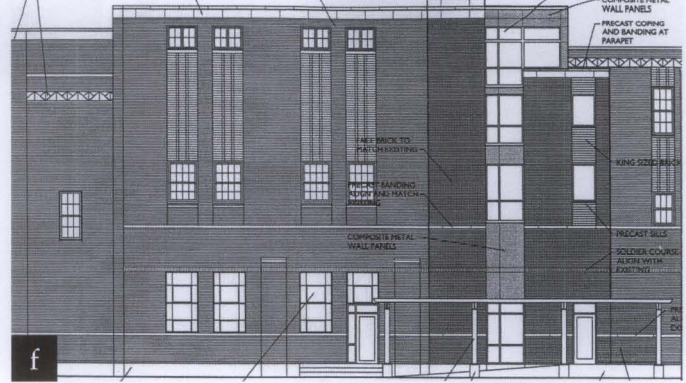
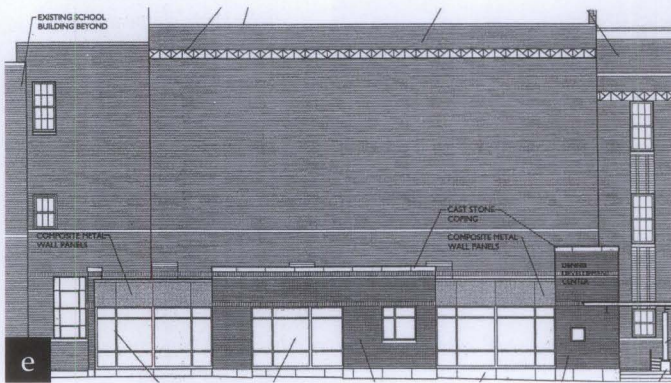
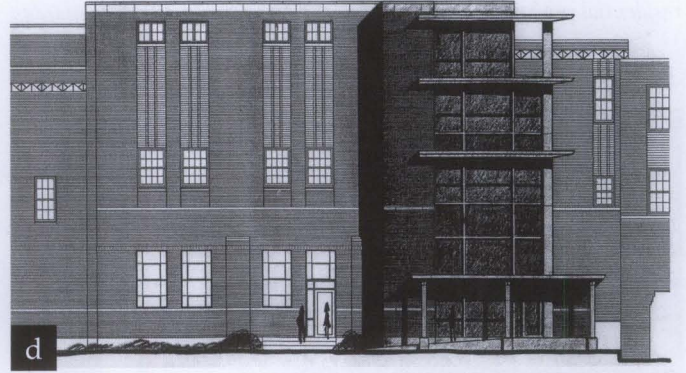
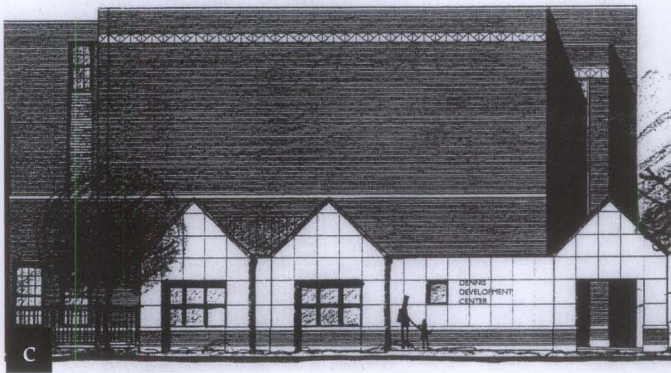


Figure 15. The rehabilitation of a c. 1930 high school auditorium for a clinic and offices proposed two additions: a one-story entrance and reception area on this elevation (a); and a four-story elevator and stair tower on another side (b). The gabled entrance (c) first proposed was not compatible with the flat-roofed auditorium and the design of the proposed stair tower (d) was also incompatible and overwhelmed the historic building. The designs were revised (e-f) resulting in new additions that meet the Standards (g-h).

## Incompatible New Additions to Historic Buildings

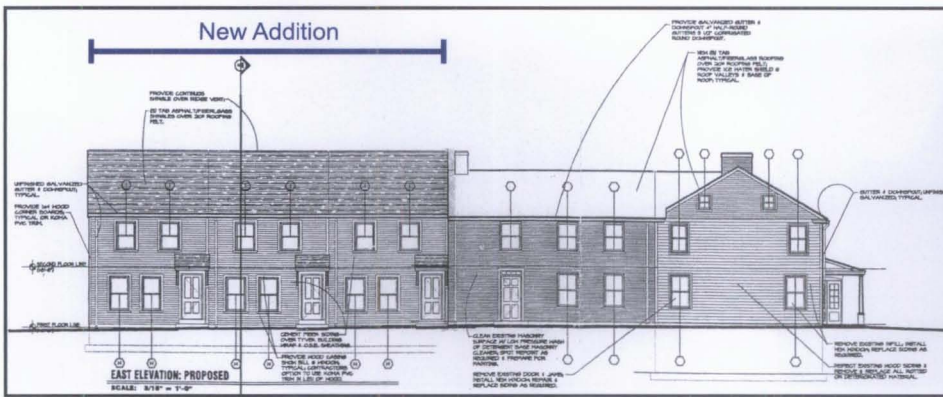


Figure 16. The proposal to add three row houses to the rear ell of this early-19th century residential property doubles its size and does not meet the Standards..



Figure 17. The small addition on the left is starkly different and it is not compatible with the eclectic, late-19th century house.



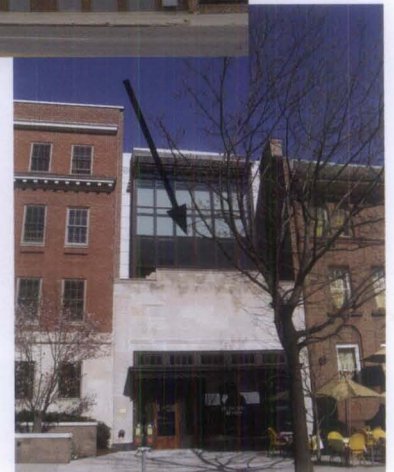
Figure 18. The expansion of a one- and one-half story historic bungalow (left) with a large two-story rear addition (right) has greatly altered and obscured its distinctive shape and form.



Figure 19. The upper two floors of this early-20th century office building were part of the original design, but were not built. During rehabilitation, the two stories were finally constructed. This treatment does not meet the Standards because the addition has given the building an appearance it never had historically.



Figure 20. The height, as well as the design, of these two-story rooftop additions overwhelms the two-story and the one-story, low-rise historic buildings.



## New Additions in Densely-Built Environments

In built-up urban areas, locating a new addition on a less visible side or rear elevation may not be possible simply because there is no available space. In this instance, there may be alternative ways to help preserve the historic character. One approach when connecting a new addition to a historic building on a primary elevation is to use a hyphen to separate them. A subtle variation in material, detailing and color may also provide the degree of differentiation necessary to avoid changing the essential proportions and character of the historic building.

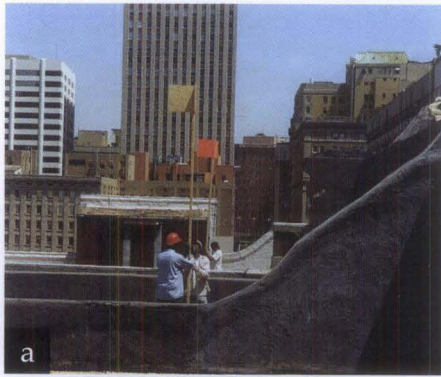
A densely-built neighborhood such as a downtown commercial core offers a particular opportunity to design an addition that will have a minimal impact on the historic building. Often the site for such an addition is a vacant lot where another building formerly stood. Treating the addition as a separate or infill building may be the best approach when designing an addition that will have the least impact on the historic building and the district. In these instances there may be no need for a direct visual link to the historic building. Height and setback from the street should generally be consistent with those of the historic building and other surrounding buildings in the district. Thus, in most urban commercial areas the addition should not be set back from the façade of the historic building. A tight urban setting may sometimes even accommodate a larger addition if the primary elevation is designed to give the appearance of being several buildings by breaking up the facade into elements that are consistent with the scale of the historic building and adjacent buildings.



Figure 21. Both wings of this historic L-shaped building (top), which fronts on two city streets, adjoined vacant lots. A two-story addition was constructed on one lot (above, left) and a six-story addition was built on the other (above, right). Like the historic building, which has two different facades, the compatible new additions are also different and appear to be separate structures rather than part of the historic building.



Figure 22. The proposed new addition is compatible with the historic buildings that remain on the block. Its design with multiple storefronts helps break up the mass.



## Rooftop Additions

The guidance provided on designing a compatible new addition to a historic building applies equally to new rooftop additions. A rooftop addition should preserve the character of a historic building by preserving historic materials, features and form; and it should be compatible but differentiated from the historic building.

However, there are several other design principles that apply specifically to rooftop additions. Generally, a rooftop addition should not be more than one story in height to minimize its visibility and its impact on the proportion and profile of the historic building. A rooftop addition should almost always be set back at least one full bay from the primary elevation of the building, as well as from the other elevations if the building is free-standing or highly visible.

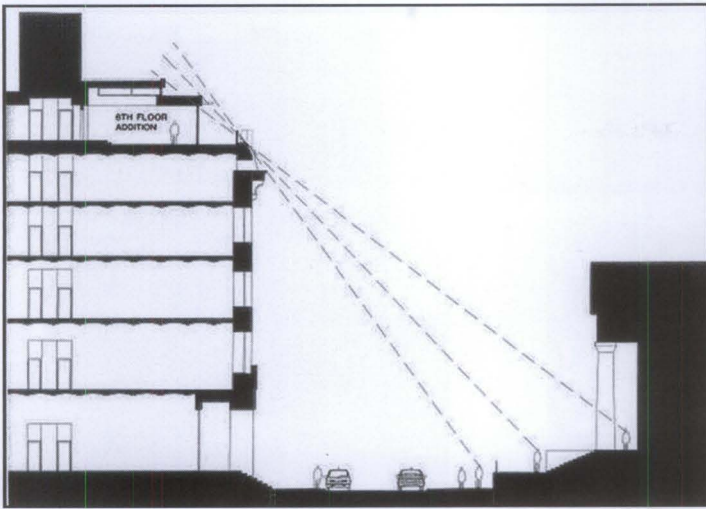
It is difficult, if not impossible, to minimize the impact of adding an entire new floor to relatively low buildings, such as small-scale residential or commercial structures, even if the new addition is set back from the plane of the façade. Constructing another floor on top of a small, one, two or three-story building is seldom appropriate for buildings of this size as it would measurably alter the building's proportions and profile, and negatively impact its historic character. On the other hand, a rooftop addition on an eight-story building, for example, in a historic district consisting primarily of tall buildings might not affect the historic character because the new construction may blend in with the surrounding buildings and be only minimally visible within the district. A rooftop addition in a densely-built urban area is more likely to be compatible on a building that is adjacent to similarly-sized or taller buildings.

A number of methods may be used to help evaluate the effect of a proposed rooftop addition on a historic building and district, including pedestrian sight lines, three-dimensional schematics and computer-generated design. However, drawings generally do not provide a true "picture" of the appearance and visibility of a proposed rooftop addition. For this reason, it is often necessary to construct a rough, temporary, full-size or skeletal mock up of a portion of the proposed addition, which can then be photographed and evaluated from critical vantage points on surrounding streets.

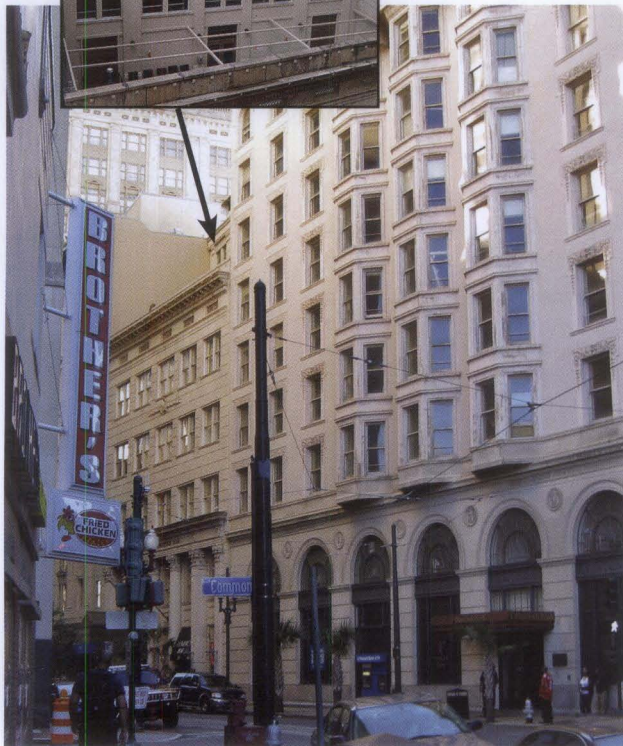


Figure 23. Colored flags marking the location of a proposed penthouse addition (a) were placed on the roof to help evaluate the impact and visibility of an addition planned for this historic furniture store (b). Based on this evaluation, the addition was constructed as proposed. It is minimally visible and compatible with the 1912 structure (c). The tall parapet wall conceals the addition from the street below (d).





**Figure 24. How to Evaluate a Proposed Rooftop Addition.**  
 A sight-line study (above) only factors in views from directly across the street, which can be very restrictive and does not illustrate the full effect of an addition from other public rights of way. A mock up (above, right) or a mock up enhanced by a computer-generated rendering (below, right) is essential to evaluate the impact of a proposed rooftop addition on the historic building.



*Figure 26. A rooftop addition would have negatively impacted the character of the primary facade (right) of this mid-19th century, four-story structure and the low-rise historic district. However, a third floor was successfully added on the two-story rear portion (below) of the same building with little impact to the building or the district because it blends in with the height of the adjacent building.*



*Figure 25. It was possible to add a compatible, three-story, penthouse addition to the roof of this five-story, historic bank building because the addition is set far back, it is surrounded by taller buildings and a deep parapet conceals almost all of the addition from below.*

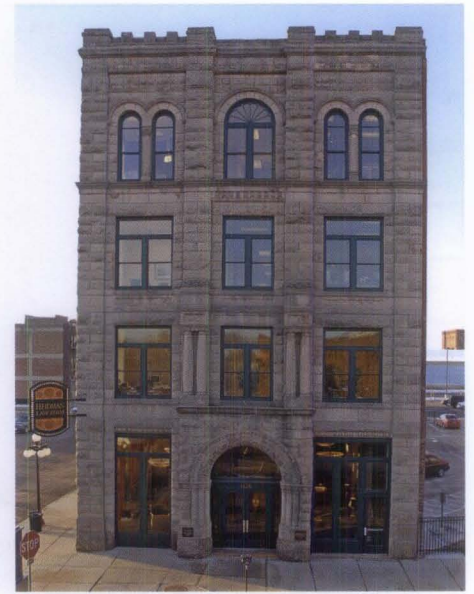


Figure 27. Although the new brick stair/elevator tower (left) is not visible from the front (right), it is on a prominent side elevation of this 1890 stone bank. The compatible addition is set back and does not compete with the historic building. Photos: Chadd Gossmann, Aurora Photography, LLC.

## Designing a New Exterior Addition to a Historic Building

This guidance should be applied to help in designing a compatible new addition that will meet the *Secretary of the Interior's Standards for Rehabilitation*:

- A new addition should be simple and unobtrusive in design, and should be distinguished from the historic building—a recessed connector can help to differentiate the new from the old.
- A new addition should not be highly visible from the public right of way; a rear or other secondary elevation is usually the best location for a new addition.
- The construction materials and the color of the new addition should be harmonious with the historic building materials.
- The new addition should be smaller than the historic building—it should be subordinate in both size and design to the historic building.

The same guidance should be applied when designing a compatible **rooftop** addition, plus the following:

- A rooftop addition is generally not appropriate for a one, two or three-story building—and often is not appropriate for taller buildings.
- A rooftop addition should be minimally visible.
- Generally, a rooftop addition must be set back at least one full bay from the primary elevation of the building, as well as from the other elevations if the building is freestanding or highly visible.
- Generally, a rooftop addition should not be more than one story in height.
- Generally, a rooftop addition is more likely to be compatible on a building that is adjacent to similarly-sized or taller buildings.

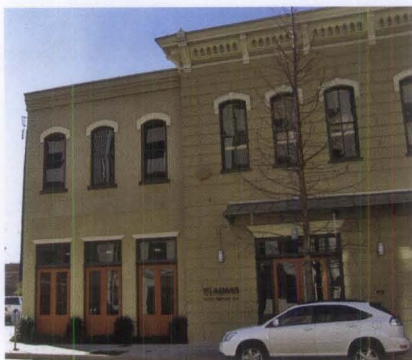


Figure 28. A small addition (left) was constructed when this 1880s train station was converted for office use. The paired doors with transoms and arched windows on the compatible addition reflect, but do not replicate, the historic building (right).



Figure 29. This simple glass and brick entrance (left) added to a secondary elevation of a 1920s school building (right) is compatible with the original structure.

## Summary

Because a new exterior addition to a historic building can damage or destroy significant materials and can change the building's character, an addition should be considered only after it has been determined that the new use cannot be met by altering non-significant, or secondary, interior spaces. If the new use cannot be met in this way, then an attached addition may be an acceptable alternative if carefully planned and designed. A new addition to a historic building should be constructed in a manner that preserves significant materials, features and form, and preserves the building's historic character. Finally, an addition should be differentiated from the historic building so that the new work is compatible with—and does not detract from—the historic building, and cannot itself be confused as historic.

## Additional Reading

Byard, Paul Spencer. *The Architecture of New Additions: Design and Regulation*. New York, NY: W.W. Norton & Company, 1998.

Day, Steven, AIA. "Modernism Meets History: New Additions to Historic Structures." *Preservation Seattle* [Historic Seattle's online monthly preservation magazine.] May 2003. [www.historicseattle.org/preservationseattle/publicpolicy/defaultmay2.htm](http://www.historicseattle.org/preservationseattle/publicpolicy/defaultmay2.htm).

*Incentives! A Guide to the Federal Historic Preservation Tax Incentives Program for Income-Producing Properties*. "Avoiding Incompatible Treatments: New Additions & Rooftop Additions." Technical Preservation Services Branch, National Park Service. Online at [www.nps.gov/history/hps/tps/](http://www.nps.gov/history/hps/tps/).

*Interpreting the Standards Bulletins (ITS)*. Technical Preservation Services Branch, National Park Service. Online at [www.nps.gov/history/hps/tps/](http://www.nps.gov/history/hps/tps/).

*New Additions to Historic Buildings*. Technical Preservation Services Branch, National Park Service. Online at [www.nps.gov/history/hps/tps/](http://www.nps.gov/history/hps/tps/).

O'Connell, Kim A. "Making Connections." *Traditional Building*. March/April 2004. (Vol. 17, No. 2), pp. 12-15.

*The Secretary of the Interior's Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings*. Washington, D.C.: U.S. Department of the Interior, National Park Service, Preservation Assistance Division, rev. 1990.

*The Secretary of the Interior's Standards for Rehabilitation & Illustrated Guidelines for Rehabilitating Historic Buildings*. (Authors: W. Brown Morton, III, Gary L. Hume, Kay D. Weeks, and H. Ward Jandl. Project Directors: Anne E. Grimmer and Kay D. Weeks.) Washington, D.C.: U.S. Department of

the Interior, National Park Service, Preservation Assistance Division, 1992. Online at [www.nps.gov/history/hps/tps/](http://www.nps.gov/history/hps/tps/).

Semes, Steven W. "Differentiated and Compatible: The Secretary's Standards revisited." *Traditional Building*. February 2009. (Vol. 22, No. 1), pp. 20-23.

Semes, Steven W. *The Future of the Past: A Conservation Ethic for Architecture, Urbanism, and Historic Preservation*. (In association with The Institute of Classical Architecture and Classical America.) New York, NY: W.W. Norton & Company, 2009.



Figure 30. The small addition on the right of this late-19th century commercial structure is clearly secondary and compatible in size, materials and design with the historic building.



Figure 31. An elevator/stair tower was added at the back of this Richardsonian Romanesque-style theater when it was rehabilitated. Rough-cut stone and simple cut-out openings ensure that the addition is compatible and subordinate to the historic building. Photo: Chuck Liddy, AIA.

## Acknowledgements

Anne E. Grimmer, Senior Architectural Historian, Technical Preservation Services Branch, National Park Service, revised *Preservation Brief 14*, written by Kay D. Weeks and first published in 1986. The revised Brief features all new illustrations and contains expanded and updated design guidance on the subject of new additions that has been developed by the Technical Preservation Services Branch since the original publication of the Brief. Several individuals generously contributed their time and expertise to review the revision of this *Preservation Brief*, including: Sharon C. Park, FAIA, Chief, Architectural History and Historic Preservation, Smithsonian Institution; Elizabeth Tune and Karen Brandt, Department of Historic Resources, Commonwealth of Virginia; and Phillip Wisley and David Ferro, Division of Historical Resources, Florida Department of State. The Technical Preservation Services professional staff, in particular Michael J. Auer, Jo Ellen Hensley, Gary Sachau and Rebecca Shiffer, also provided important guidance in the development of this publication. All illustrations are from National Park Service files unless otherwise credited. Front cover image: Detail of new addition shown in Figure 4. Photo: © Maxwell MacKenzie.

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. The Technical Preservation Services Branch, National Park Service, prepares standards, guidelines and other educational materials on responsible historic preservation treatments for a broad public audience. Additional information about the programs of Technical Preservation Services is available on the website at [www.nps.gov/history/hps/tps](http://www.nps.gov/history/hps/tps). Comments about this publication should be addressed to: Charles E. Fisher, Technical Preservation Publications Program Manager, Technical Preservation Services-2255, National Park Service, 1849 C Street, NW, Washington, DC 20240. This publication is not copyrighted and can be reproduced without penalty. Normal procedures for credit to the author and the National Park Service are appreciated.

# 15 PRESERVATION BRIEFS

## Preservation of Historic Concrete

Paul Gaudette and Deborah Slaton



National Park Service  
U.S. Department of the Interior  
Heritage Preservation Services



### Introduction to Historic Concrete

Concrete is an extraordinarily versatile building material used for utilitarian, ornamental, and monumental structures since ancient times. Composed of a mixture of sand, gravel, crushed stone, or other coarse material, bound together with lime or cement, concrete undergoes a chemical reaction and hardens when water is added. Inserting reinforcement adds tensile strength to structural concrete elements. The use of reinforcement contributes significantly to the range and size of building and structure types that can be constructed with concrete.

While early twentieth century proponents of modern concrete often considered it to be permanent, it is, like all materials, subject to deterioration. This Brief provides an overview of the history of concrete and its popularization in the United States, surveys the principal causes and modes of concrete deterioration, and outlines approaches to repair and protection that are appropriate to historic concrete. In the context of this Brief, historic concrete is considered to be concrete used in construction of structures of historical, architectural, or engineering interest, whether those structures are old or relatively new.

### Brief History of Use and Manufacture

The ancient Romans found that a mixture of lime putty and pozzolana, a fine volcanic ash, would harden under water. The resulting hydraulic cement became a major feature of Roman building practice, and was used in many buildings and engineering projects such as bridges and aqueducts. Concrete technology was kept alive during the Middle Ages in Spain and Africa. The Spanish introduced a form of concrete to the New World in the first decades of the sixteenth century, referred to as "tapia" or "tabby." This material, a mixture of lime, sand, and shell or stone aggregate

mixed with water, was placed between wooden forms, tamped, and allowed to dry in successive layers. Tabby was later used by the English settlers in the coastal southeastern United States.

The early history of concrete was fragmented, with developments in materials and construction techniques occurring on different continents and in various countries. In the United States, concrete was slow in achieving widespread acceptance in building construction and did not begin to gain popularity until the late nineteenth century. It was more readily accepted for use in transportation and infrastructure systems.

The Erie Canal in New York is an example of the early use of concrete in transportation in the United States. The natural hydraulic cement used in the canal construction was processed from a deposit of limestone found in 1818 near Chittenango, southeast of Syracuse. The use of concrete in residential construction was



Figure 1. The Sebastopol House in Seguin, Texas, is an 1856 Greek Revival-style house constructed of lime concrete. Lime concrete or "limecrete" was a popular construction material, as it could be made inexpensively from local materials. By 1900, the town had approximately ninety limecrete structures, twenty of which remain. Photo: Texas Parks and Wildlife Department.



*Figure 2. Chatterton House was the home of the post trader at Fort Fred Steel in Wyoming, one of several forts established in the 1860s to protect the Union Pacific Railroad. The walls of the post trader's house were built using stone aggregate and lime, without cement. The use of this material presents special preservation challenges.*

publicized in the second edition of Orson S. Fowler's *A Home for All* (1853) which described the advantages of "gravel wall" construction to a wide audience. The town of Seguin, Texas, thirty-five miles east of San Antonio, already had a number of concrete buildings by the 1850s and came to be called "The Mother of Concrete Cities," with approximately ninety concrete buildings made from local "lime water" and gravel (Fig. 1).

Impressed by the economic advantages of poured gravel wall or "lime-grout" construction, the Quartermaster General's Office of the War Department embarked on a campaign to improve the quality of building for frontier military posts. As a result, lime-grout structures were constructed at several western posts soon after the Civil War, including Fort Fred Steele and Fort Laramie, both in Wyoming (Fig. 2). By the 1880s, sufficient experience had been gained with unreinforced concrete to permit construction of much larger buildings. A notable example from this period is the Ponce de Leon Hotel in St. Augustine, Florida.

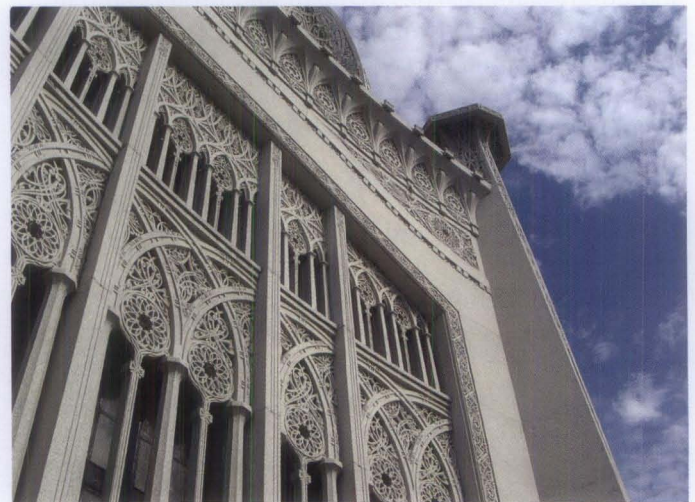


*Figure 3. The Lincoln Highway Association promoted construction of a high quality continuous hard surface roadway across the country. The Boys Scouts of America installed concrete road markers along the Lincoln Highway in 1928.*

Extensive construction in concrete also occurred through the system of coastal fortifications commissioned by the federal government in the 1890s for the Atlantic, Pacific, and Gulf coasts. Unlike most concrete construction to that time, the special requirements of coastal fortifications called for concrete walls as much as 20 feet thick, often at sites that were difficult to access. Major structures in the coastal defenses of the 1890s were built of mass concrete with no internal reinforcing, a practice that was replaced by the use of reinforcing bars in fortifications constructed after about 1905.

The use of reinforced concrete in the United States dates from 1860, when S.T. Fowler obtained a patent for a reinforced concrete wall. In the early 1870s, William E. Ward built his own house in Port Chester, New York, using concrete reinforced with iron rods for all structural elements. Despite these developments, such construction remained a novelty until after 1880, when innovations introduced by Ernest L. Ransome made the use of reinforced concrete more practicable. Ransome made many contributions to the development of concrete construction technology, including the use of twisted reinforcing bars to improve bond between the concrete and the steel, which he patented in 1884. Two years later, Ransome introduced the rotary kiln to United States cement production. The new kiln had greater capacity and burned more thoroughly and uniformly, allowing development of a less expensive, more uniform, and more reliable manufactured cement. Improvements in concrete production initiated by Ransom led to a much greater acceptance of concrete after 1900.

The Lincoln Highway Association, incorporated in 1913, promoted the use of concrete in construction of a coast-to-coast roadway system. The goal of the Lincoln Highway Association and highway advocate Henry B. Joy was to educate the country in the need for good roads made of concrete, with an improved Lincoln



*Figure 4. The highly ornamental concrete panels on the exterior facade of the Baha'i House of Worship in Wilmette, Illinois, illustrate the work of fabricator John J. Earley, known as "the man who made concrete beautiful."*



Figure 5. Following World War II, architects and engineers took advantage of improvements in concrete production, quality control, and advances in precast concrete to design structures such as the Police Headquarters building in Philadelphia, Pennsylvania, constructed in 1961. Photo: Courtesy of the Philadelphia Police Department.

Highway as an example. Concrete “seedling miles” were constructed in remote areas to emphasize the superiority of concrete over unimproved dirt. The Association believed that as people learned about concrete, they would press the government to construct good roads throughout their states. Americans’ enthusiasm for good roads led to the involvement of the federal government in road-building and the creation of numbered U.S. routes in the 1920s (Fig. 3).

During the early twentieth century, Ernest Ransome in Beverly, Massachusetts, Albert Kahn in Detroit, and Richard E. Schmidt in Chicago, promoted concrete for use in “Factory Style” utilitarian buildings with an exposed concrete frame infilled with expanses of glass. Thomas Edison’s cast-in-place reinforced concrete homes in Union Township, New Jersey (1908), proclaimed a similarly functional emphasis in residential construction. From the 1920s onward, concrete began to be used with spectacular design results: examples include John J. Earley’s Meridian Hill Park in Washington, D.C.; Louis Bourgeois’ exuberant, graceful Baha’i Temple in Wilmette, Illinois (1920–1953), for which Earley fabricated the concrete (Fig. 4); and Frank Lloyd Wright’s Fallingwater near Bear Run, Pennsylvania (1934). Continuing improvements in quality control and development of innovative fabrication processes, such as the Shockbeton method for precast concrete, provided increasing opportunities for architects and engineers. Wright’s Guggenheim Museum in New York City (1959); Geddes Brecher Qualls & Cunningham’s Police Headquarters building in Philadelphia, Pennsylvania (1961); and Eero Saarinen’s soaring terminal building at Dulles International Airport outside Washington, D.C., and the TWA terminal at Kennedy Airport in New York (1962), exemplify the masterful use of concrete achieved in the modern era (Fig. 5).



Figure 6. The Bailey Magnet School in Jackson, Mississippi, was designed as the Jackson Junior High School by the firm of N.W. Overstreet & Town in 1936. The streamlined building exemplifies the applicability of concrete to creating a modern architectural aesthetic. Photo: Bill Burris, Burris/Wagnon Architects, P.A.



Figure 7. Detailed bas reliefs as well as sculptures, such as this lion at the Bailey Magnet School, could be used as ornamentation on concrete buildings. Sculptural concrete elements were typically cast in molds.

Throughout the twentieth century, a wide range of architectural and engineering structures were built using concrete as a practical and cost-effective choice—and concrete also became valued for its aesthetic qualities. Cast in place and precast concrete were readily adapted to the Streamlined Moderne style, as exemplified by the Bailey Magnet School in Jackson, Mississippi, designed as the Jackson Junior High School by N.W. Overstreet & Town in 1936 (Figs. 6 and 7). The school is one of many concrete buildings designed and constructed under the auspices of the Public Works Administration. Recreational structures and landscape features also utilized the structural range and unique character of exposed concrete to advantage, as seen in Chicago’s Lincoln Park Chess Pavilion, designed by Morris Webster in 1956 (Fig. 8), and the Ira C. Keller Fountain in Portland Oregon, designed by Lawrence Halprin in 1969 (Fig. 9). Concrete was also popular for building interiors, with ornamental features and exposed structural elements recognized as part of the design aesthetic (See Figs. 10 and 11 in sidebar).

## Historic Interiors

The expanded use of concrete provided new opportunities to create dramatic spaces and ornate architectural detail on the interiors of buildings, at a significant cost savings over traditional construction practices. The architectural design of the Berkeley City Club in Berkeley, California, expressed Moorish and Gothic elements in concrete on the interior of the building (Fig. 10). Used as a woman's social club, the building was designed by noted California architect Julia Morgan and constructed in 1929. The vaulted ceilings, columns, and ornamental capitals of the lobby and the ornamental arches and beamed ceiling of the "plunge" are all constructed of concrete.



Figure 10. The Berkeley City Club has significant interior spaces and features of concrete construction, including the lobby and pool. Photos: Una Gilmartin (left) and Brian Kehoe (right), Wiss, Janney, Elstner Associates, Inc.

The historic character of a building's interior can also be conveyed in a more utilitarian manner in terms of concrete features and finishes (Fig. 11). The exposed concrete structure—columns, capitals, and drop panels—is an integral part of the character of this old commercial building in Minneapolis. In concrete warehouse and factory buildings of the early twentieth century, exposed concrete columns and formboard finish concrete slab ceilings are common features as seen in this warehouse, now converted for use as a parking garage and shops.



Figure 11. Whether in a circa 1925 office (left) or in a parking garage and retail facility (right), exposed concrete structures help characterize these building interiors. Photo: Minnesota Historical Society (left).

## Concrete Characteristics

Concrete is composed of fine (sand) and coarse (crushed stone or gravel) aggregates and paste made of portland cement and water. The predominant material in terms of bulk is the aggregate. Portland cement is the binder most commonly used in modern concrete. It is commercially manufactured by blending limestone or chalk with clays that contain alumina, silica, lime, iron oxide and magnesia, and heating the compounds together to high temperatures. The hydration process that occurs between the portland cement and water results in formation of an alkali paste that surrounds and binds the aggregate together as a solid mass.

The quality of the concrete is dependent on the ratio of water to the binder; binder content; sound, durable, and well-graded aggregates; compaction during placement; and proper curing. The amount of water used in the mix affects the concrete permeability and strength. The use of excess water beyond that required in the hydration process results in more permeable concrete, which is more susceptible to weathering and deterioration. Admixtures are commonly added to concrete to adjust concrete properties such as setting or hardening time, requirements for water, workability, and other characteristics. For example, the advent of air entraining agents in the 1930s provided enhanced durability for concrete.

During the twentieth century, there was a steady rise in the strength of ordinary concrete as chemical processes became better understood and quality control measures improved. In addition, the need to protect embedded reinforcement against corrosion was acknowledged. Requirements for concrete cover over reinforcing steel, increased cement content, decreased water-cement ratio, and air entrainment all contributed to greater concrete strength and improved durability.

## Mechanisms and Modes of Deterioration

### Causes of Deterioration

Concrete deterioration occurs primarily because of corrosion of the embedded steel, degradation of the concrete itself, use of improper techniques or materials in construction, or structural problems. **The causes of concrete deterioration must be understood in order to select an appropriate repair and protection system.**



While reinforcing steel has played a pivotal role in expanding the applications of concrete in twentieth century architecture, corrosion of this steel has also caused deterioration in many historic structures. Reinforcing steel embedded in the concrete is normally surrounded by a passivating oxide layer that, when present, protects the steel from corrosion and aids in bonding the steel and concrete. When the concrete's normal alkaline environment (above a pH of 10) is compromised and the steel is exposed to water, water vapor, or high relative humidity, corrosion of the steel reinforcing takes place. A reduction in alkalinity results from carbonation, a process that occurs when the carbon dioxide in the atmosphere reacts with calcium hydroxide and moisture in the concrete. Carbonation starts at the concrete's exposed surface but may extend to the reinforcing steel over time. When carbonation reaches the metal reinforcement, the concrete no longer protects the steel from corrosion.

Corrosion of embedded reinforcing steel may be initiated and accelerated if calcium chloride was added to the concrete as a set accelerator during original construction to promote more rapid curing. It may also take place if the concrete is later exposed to deicing salts, as may occur during the winter in northern climates. Seawater or other marine environments can also provide large amounts of chloride, either from inadequately washed original aggregate or from exposure of the concrete to seawater.

Corrosion-related damage to reinforced concrete is the result of rust, a product of the corrosion process of steel, which expands and thus requires more space in the concrete than the steel did at the time of installation. This change in volume of the steel results in expansive forces, which cause cracking and spalling of the adjacent concrete (Fig. 12). Other signs of corrosion of embedded steel include delamination of the concrete (planar separations parallel to the surface) and rust staining (often a precursor to spalling) on the concrete near the steel.

Lack of proper maintenance of building elements such as roofs and drainage systems can contribute to water-related deterioration of the adjacent concrete, particularly when concrete is saturated with water and then exposed to freezing temperatures. As water within the concrete freezes, it expands and exerts forces on the adjacent concrete. Repeated freezing and thawing can result in the concrete cracking and delaminating. Such damage appears as surface degradation, including severe scaling and micro-cracking that extends into the concrete. The condition is most often observed near the surface of the concrete but can also eventually occur deep within the concrete. This type of deterioration is usually most severe at joints, architectural details, and other areas with more surface exposure to weather. In the second half of the twentieth century, concrete has utilized entrained air (the incorporation of microscopic air bubbles) to provide enhanced protection against damage due to cyclic freezing of saturated concrete.

The use of certain aggregates can also result in deterioration of the concrete. Alkali-aggregate reactions—in some cases alkali-silica reaction (ASR)—occur when alkalis normally present in cement react with certain aggregates, leading to the development of an expansive crystalline gel. When this gel is exposed to moisture, it expands and causes cracking of the aggregate and concrete matrix. Deleterious

aggregates are typically found only in certain areas of the country and can be detected through analysis by an experienced petrographer. Low-alkali cements as well as fly ash are used today in new construction to prevent such reactions where this problem may occur.

### *Problems Specifically Encountered with Historic Concrete*

Materials and workmanship used in the construction of historic concrete structures, particularly those built before the First World War, sometimes present potential sources of problems. For example, where the aggregate consisted of cinder from burned coal or crushed brick,



*Figure 8. The Chess Pavilion in Chicago's Lincoln Park was designed by architect Morris Webster and constructed in 1956. The pavilion is a distinctive landscape feature, with its reinforced concrete cantilevered slab that provides cover for chess players.*



*Figure 9. The Ira C. Keller Fountain in Portland, Oregon, was designed by Lawrence Halprin and constructed in 1969. The fountain is constructed primarily of concrete pillars with formboard textures and surrounding elements, patterned with geometric lines, which facilitate the path of water. Photo: Anita Washko, Wiss, Janney, Elstner Associates, Inc.*



Figure 12. The concrete lighthouse at the Kilauea Point Light Station, Kilauea, Kauai, Hawaii, was constructed circa 1913. The concrete, which was a good quality, high strength mix for its day, is in good condition after almost one hundred years in service. Deterioration in the form of spalling related to corrosion of embedded reinforcing steel has occurred primarily in areas of higher ornamentation such as projecting bands and brackets (see close-up photo).

the concrete tends to be weak and porous because these aggregates absorb water. Some of these aggregates can be extremely susceptible to deterioration when exposed to moisture and cyclic freezing and thawing. Concrete was sometimes compromised by inclusion of seawater or beach sand that was not thoroughly washed with fresh water, a condition more common with coastal fortifications built prior to 1900. The sodium chloride present in seawater and beach sand accelerates the rate of corrosion of the reinforced concrete.

Another problem encountered with historic concrete is related to poor consolidation of the

concrete during its placement in forms, or in molds in the case of precasting. This problem is especially prevalent in highly ornamental units. Early twentieth century concrete was often tamped or rodded into place, similar to techniques used in forming cast stone. Poorly consolidated concrete often contains voids (“bugholes” or “honeycombs”), which can reduce the protective concrete cover over the embedded reinforcing bars, entrap water, and, if sufficiently large and strategically numerous, reduce localized concrete strength. Vibration technology has improved over time and flowability agents are also used today to address this problem.

A common type of deterioration observed in concrete is the effect of weathering from exposure to wind, rain, snow, and salt water or spray. Weathering appears as erosion of the cement paste, a condition more prevalent in northern regions where precipitation can be highly acidic. This results in the exposure of the aggregate particles on the exposed concrete surface. Variations may occur in the aggregate exposure due to differential erosion or dissolution of exposed cement paste. Erosion can also be caused by the mechanical action of water channeled over concrete, such as by the lack of drip grooves in belt courses and sills, and by inadequate drainage. In addition, high-pressure water when used for cleaning can also erode the concrete surface.

In concrete structures built prior to the First World War, concrete was often placed into forms in relatively short vertical lifts due to limitations in lifting and pouring techniques available at the time. Joints between different concrete placements (often termed cold joints or lift lines) may sometimes be considered an important part of the character of a concrete element (Fig. 13). However, wide joints may permit water to infiltrate the concrete, resulting in more rapid paste erosion or freeze-thaw deterioration of adjacent concrete in cold climates.

In the early twentieth century, concrete was sometimes placed in several layers parallel to the exterior surface. A base concrete was first created with formwork and then a more cement rich mortar layer was applied to the exposed vertical face of the



Figure 13. Fort Casey on Admiralty Head, Fort Casey, Washington, was constructed in 1898. The lift lines from placement of concrete are clearly visible on the exterior walls and characterize the finished appearance.

base concrete. The higher cement content in the facing concrete provided a more water-resistant outer layer and finished surface. The application of a cement-rich top layer, referred to in some early concrete publications as "waterproofing," was also used on top surfaces of concrete walls, or as the top layer in sidewalks. With this type of concrete construction, deterioration can occur over time as a result of debonding between layers, and can proceed very rapidly once the protective cement-rich layer begins to break down.

It is common for historic concrete to have a highly variable appearance, including color and finish texture. Different levels of aggregate exposure due to paste erosion are often found in exposed aggregate concrete. This variability in the appearance of historic concrete increases the level of difficulty in assessing and repairing weathered concrete.

### *Signs of Distress and Deterioration*

Characteristic signs of failure in concrete include cracking, spalling, staining, and deflection. Cracking occurs in most concrete but will vary in depth, width, direction, pattern, and location, and can be either active or dormant (inactive). Active cracks can widen, deepen, or migrate through the concrete, while dormant cracks remain relatively unchanged in size. Some dormant cracks, such as those caused by early age shrinkage of the concrete during curing, are not a structural concern but when left unrepaired, can provide convenient channels for moisture penetration and subsequent damage. Random surface cracks, also called map cracks due to their resemblance to lines on a map, are usually related to early-age shrinkage but may also indicate other types of deterioration such as alkali-silica reaction.

Structural cracks can be caused by temporary or continued overloads, uneven foundation settling, seismic forces, or original design inadequacies. Structural cracks are active if excessive loads are applied to a structure, if the overload is continuing, or if settlement is ongoing. These cracks are dormant if the temporary overloads have been removed or if differential settlement has stabilized. Thermally-induced cracks result from stresses produced by the expansion and contraction of the concrete during temperature changes. These cracks frequently occur at the ends or re-entrant corners of older concrete structures that were built without expansion joints to relieve such stress.

Spalling (the loss of surface material) is often associated with freezing and thawing as well as cracking and delamination of the concrete cover over embedded reinforcing steel. Spalling occurs when reinforcing bars corrode and the corrosion by-products expand, creating high stresses on the adjacent concrete, which cracks and is displaced. Spalling can also occur when water absorbed by the concrete freezes and thaws (Fig. 14). In addition, surface spalling or scaling may result from the improper finishing, forming, or other surface



*Figures 14. Layers of architectural concrete that have debonded (spalled) from the surface were removed from a historic water tank during the investigation performed to assess existing conditions. Photos: Anita Washko, Wiss, Janney, Elstner Associates, Inc.*

phenomena when water-rich cement paste (laitance) rises to the surface. The resulting weak material is vulnerable to spalling of thin layers, or scaling. In some cases, spalling of the concrete can diminish the load-carrying capacity of the structure.

Deflection is the bending or sagging of structural beams, joists, or slabs, and can be an indication of deficiencies in the strength and structural soundness of concrete. This condition can be produced by overloading, corrosion of embedded reinforcing, or inadequate design or construction, such as use of low-strength concrete or undersized reinforcing bars.

Staining of the concrete surface can be related to soiling from atmospheric pollutants or other contaminants, dirt accumulation, and the presence of organic growth. However, stains can also indicate more serious underlying problems, such as corrosion of embedded reinforcing steel, improper previous surface treatments, alkali-aggregate reaction, or efflorescence, the deposition of soluble salts on the surface of the concrete as a result of water migration (Fig. 15).

## Planning for Concrete Preservation

The significance of a historic concrete building or structure—including whether it is important for its architectural or engineering design, for its materials and construction techniques, or both—guides decision making about repair and, if needed, replacement methods. Determining the causes of deterioration is also central to the development of a conservation and repair plan. With historic concrete buildings, one of the more difficult challenges is allowing for sufficient time during the planning phase to analyze the concrete, develop mixes, and provide time for adequate aging of mock-ups for matching to the original concrete.

An understanding of the original construction techniques (cement characteristics, mix design, original intent of assembly, type of placement, precast versus cast in place, etc.) and previous repair work performed on the concrete is important in determining causes of existing deterioration and the susceptibility of the structure to potential other types of deterioration. For example, concrete placed in short lifts (individual concrete placements) or constructed in precast segments will have numerous joints that can provide entry points for water infiltration. Inappropriate prior repairs, such as installation of patches using an incompatible material, can affect the future performance of the concrete. Such prior repairs may require corrective work.

As with other preservation projects, three primary approaches are usually considered for historic concrete structures: *maintenance, repair, or replacement*. Maintenance and repair best achieve the preservation goal of minimal intervention and the greatest retention of existing historic fabric. However, where elements of the building are severely deteriorated or where inherent problems with the material lead to ongoing failures, replacement may be necessary.

During planning, information is gathered through research, visual survey, inspection openings, and laboratory studies. The material should then be reviewed by professionals experienced in concrete deterioration to help evaluate the nature and causes of the concrete problems, to assess both the short-term and long-term effects of the deterioration, and to formulate proper repair approaches.

### Condition Assessment

A condition assessment of a concrete building or structure should begin with a review of all available documents related to original construction and prior repairs. While plans and specifications for older concrete buildings are not always available, they can be an invaluable resource and every attempt should be made to find them. They may provide information on the composition of the concrete mix or on the type and location of reinforcing bars. If available, documents related to past repairs should also be reviewed to



Figure 15. Evidence of moisture movement through concrete is apparent in the form of mineral deposits on the concrete surface. Cyclic freezing and thawing of entrapped moisture, and corrosion of embedded reinforcement, have also contributed to deterioration of the concrete column on this fence at Crocker Field in Fitchburg, Massachusetts, designed by the Olmsted Brothers.

understand how the repairs were made and to help evaluate their anticipated performance and service life. Archival photographs can also provide a valuable source of information about original construction.

A visual condition survey will help identify and evaluate the extent, types, and patterns of distress and deterioration. The American Concrete Institute offers several useful guides on how to perform a visual condition survey of concrete. Generally, the condition assessment begins with an overall visual survey, followed by a close-up investigation of representative areas to obtain more detailed information about modes of deterioration.

A number of nondestructive testing methods can be used in the field to evaluate concealed conditions. Basic techniques include sounding with a hand-held hammer (or for horizontal surfaces, a chain) to help identify areas of delamination. More sophisticated techniques include impact-echo testing (Fig. 16), ground penetrating radar, pulse velocity, and other methods that characterize concrete thickness and locate voids or delaminations. Magnetic detection instruments are used to locate embedded reinforcing steel and can be calibrated to identify the size and depth of reinforcement. Corrosion measurements can be taken using copper-copper sulfate half-cell tests or linear polarization techniques to determine the probability or rate of active corrosion of the reinforcing steel.

To further evaluate the condition of the concrete, samples may be removed for laboratory study to determine material components and composition, and causes of deterioration. Samples need to be representative of existing conditions but should be taken from unobtrusive locations. Laboratory studies of the concrete may include petrographic evaluation following ASTM C856, *Practice for Petrographic Examination of Hardened Concrete*. Petrographic examination, consisting of microscopical studies performed by a geologist specializing in the evaluation of construction materials, is performed to determine air content, water-cement ratio, cement content, and general aggregate characteristics. Laboratory studies can also include

chemical analyses to determine chloride content, sulfate content, and alkali levels of the concrete; identification of deleterious aggregates; and determination of depth of carbonation. Compressive strength studies can be conducted to evaluate the strength of the existing concrete and provide information for repair work. The laboratory studies provide a general identification of the original concrete's components and aggregates, and evidence of damage due to various mechanisms including cyclic freezing and thawing, alkali-aggregate reactivity, or sulfate attack. Information gathered through laboratory studies can also be used to help develop a mix design for the repair concrete.

## Cleaning

As with other historic structures, concrete structures are cleaned for several reasons: to improve the appearance of the concrete, as a cyclical maintenance measure, or in preparation for repairs. Consideration should first be given to whether the historic concrete structure needs to be cleaned at all. If cleaning is required, then the gentlest system that will be effective should be selected.

Three primary methods are used for cleaning concrete: water methods, abrasive surface treatments, and chemical surface treatments. Low-pressure water (less than 200 psi) or steam cleaning can effectively remove surface soiling from sound concrete; however, care is required on fragile or deteriorated surfaces. In addition, water and steam methods are typically not effective in removing staining or severe soiling. Power washing with high-pressure water is sometimes used to clean or remove coatings from sound, high-strength concrete, but high-pressure water washing is generally damaging to and not appropriate for concrete on historic structures.

When used with proper controls and at very low pressures (typically 35 to 75 psi), microabrasive



Figure 16. Impact echo testing is performed on a concrete structural slab to help determine depth of deterioration. In this method, a short pulse of energy is introduced into the structure and a transducer mounted on the impacted surface of the structure receives the reflected input waves or echoes. These waves are analyzed to help identify flaws and deterioration within the concrete.

surface treatments using very fine particulates, such as dolomitic limestone powder, can sometimes clean effectively. However, microabrasive cleaning may alter the texture and surface reflectivity of concrete. Some concrete can be damaged even by fine particulates applied at very low pressures.

Chemical surface treatments can clean effectively but may also alter the appearance of the concrete by bleaching the concrete, removing the paste, etching the aggregate, or otherwise altering the surface. Detergent cleaners or mild, diluted acid cleaners may be appropriate for removal of staining or severe soiling. Cleaning products that contain strong acids such as hydrochloric (muriatic) or hydrofluoric acid, which will damage concrete and are harmful to persons, animals, site features, and the environment, should not be used.

For any cleaning process, trial samples should be performed prior to full-scale implementation. The intent of the cleaning program should not be to return the structure to a like new appearance. Concrete can age gracefully, and as long as soiling is not severe or deleterious, many structures can still be appreciated without extensive cleaning.

## Methods of Maintenance and Repair

The maintenance of historic concrete often is thought of in terms of appropriate cleaning to remove unattractive dirt or soiling materials. However, the implementation of an overall maintenance plan for a historic structure is the most effective way to help protect historic concrete. For examples, the lack of maintenance to roofs and drainage systems can promote water related damage to adjacent concrete features. The repeated use of deicing salts in winter climates can pit the surface of old concrete and also may promote decay in embedded steel reinforcements. Inadequate protection of concrete walls adjacent to driveways and parking areas can result in the need for repair work later on.

The maintenance of historic concrete involves the regular inspection of concrete to establish baseline conditions and identify needed repairs. Inspection tasks involve monitoring protection systems, including sealant joints, expansion joints, and protective coatings; reviewing existing conditions for development of distress such as cracking and delaminations; documenting conditions observed; and developing and implementing a cyclical repair program.

Sealants are an important part of maintenance of historic concrete structures. Elastomeric sealants, which have replaced traditional oil-resin based caulks for many applications, are used to seal cracks and joints to keep out moisture and reduce air infiltration. Sealants are commonly used at windows and door perimeters, at interfaces between concrete and other materials, and at attachments to or through walls or roofs, such as with lamps, signs, or exterior plumbing fixtures.

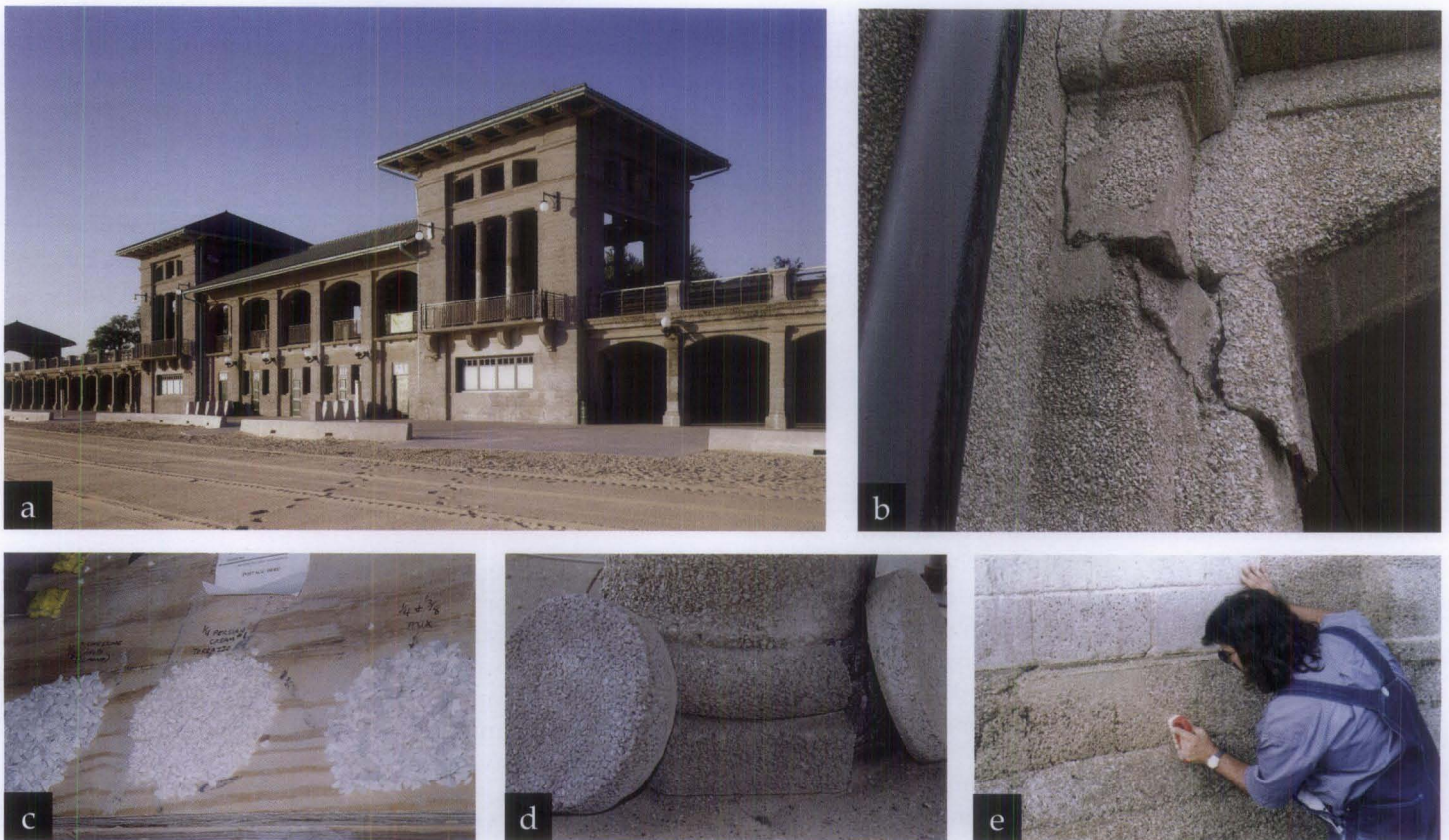


Figure 17. (a) The 63rd Street Beach House was constructed on the shoreline of Chicago in 1919. The highly exposed aggregate concrete of the exterior walls of the beach house was used for many buildings in the Chicago parks as an alternative to more expensive stone construction. Photo: Leslie Schwartz Photography. (b) Concrete deterioration included cracking, spalling, and delamination caused by corrosion of embedded reinforcing steel and concrete damage due to cyclic freezing and thawing. (c) Various sizes and types of aggregates were reviewed for matching to the original concrete materials. (d) Mock-ups of the concrete repair mix were prepared for comparison to the original concrete. Considerations included aggregate type and size, cement color, proportions, aggregate exposure, and surface finish. (e) The craftsman finished the surface to replicate the original appearance in a mock-up on the structure. Here, he used a nylon bristle brush to remove loose paste and expose the aggregate, creating a variable surface to match the adjacent original concrete.

Where used for crack repairs on historic facades, the finished appearance of the sealant application must be considered, as it may be visually intrusive. In some cases, sand can be broadcast onto the surface of the sealant to help conceal the repair.

Urethane and polyurethane sealants are often used to seal joints and cracks in concrete structures, paving, and walkways; these sealants provide a service life of up to ten years. High-performance silicone sealants also are often used with concrete, as they provide a range of movement capabilities and a service life of twenty years or more. Some silicone sealants may stain adjacent materials, which may be a problem with more porous concrete, and may also tend to accumulate dust and dirt. The effectiveness of sealants for sealing joints and cracks depends on numerous factors including proper surface preparation and application. Sealants should be examined as part of routine maintenance inspections, as these materials deteriorate faster than their substrates and must be replaced periodically as a part of cyclical maintenance.

Repair of historic concrete may be required to address deterioration because the original design and

construction did not provide for long-term durability, or to facilitate a change in use of the structure. Examples include increasing concrete cover to protect reinforcing steel and reducing water infiltration into the structure by repair of joints. Any such improvements must be thoroughly evaluated for compatibility with the original design and appearance. Care is required in all aspects of historic concrete repair, including surface preparation; installation of formwork; development of the concrete mix design; and concrete placement, consolidation, and curing.

An appropriate repair program addresses existing distress and reduces the rate of future deterioration, which in many cases involves moisture-related issues. The repair program should incorporate materials and methods that are sympathetic to the existing materials in character and appearance, and which provide good long-term performance. In addition, repair materials should age and weather similarly to the original materials. In order to best achieve these goals, concrete repair projects should be divided into three phases: development of trial repair procedures, trial repairs and evaluation, and production repair work.

For any concrete repair project, the process of investigation, laboratory analysis, trial samples, mock-ups, and full-scale repairs allows ongoing refinement of the repair work as well as implementation of quality-control measures. The trial repair process provides an opportunity for the owner, architect, engineer, and contractor to evaluate the concrete mix design and the installation and finishing techniques for the repairs from both technical and aesthetic standpoints.

The final repair materials and procedures should match the original concrete in appearance while meeting the established criteria for durability. Information gathered through trial repairs and mock-ups is invaluable in refining the construction documents prior to the start of the overall repair project (Fig. 17).

### Surface Preparation

In undertaking surface preparation for historic concrete repair, care must be taken to limit removal of existing material while still providing an appropriate substrate for repairs. This is particularly important where ornamentation and fine details are involved. Preparation for localized repairs usually begins with removal of the loose concrete to determine the general extent of the repair, followed by saw-cutting the perimeter of the repair area. The repair area should extend beyond the area of concrete deterioration to a sufficient extent to provide a sound substrate. When repairing concrete with an exposed aggregate or other special surface texture, a sawcut edge may be too visually evident. To hide the repair edge, techniques such as lightly hand-chipping the edge of the patch may be used to conceal the joint between the original concrete and the new repair material. The depth to which the concrete needs to be removed may be difficult to determine without invasive probing in the repair area. Removal of concrete should typically extend beyond the level of the reinforcing steel, if present, so that the patch encapsulates the reinforcing steel, which provides mechanical attachment for the repair.

If the concrete was originally of lower strength and quality, the assessment of present soundness is more difficult. Deteriorated and unsound concrete is typically removed using pneumatic chipping hammers. Removal of concrete in historic structures is better controlled by using smaller chipping hammers or hand tools. The area of the concrete to be repaired and the exposed reinforcing steel are then cleaned, usually by careful sandblast and air blast procedures applied only within the repair area. Adjacent original concrete surfaces should be protected during this work. In some cases, project constraints such as dust control may limit the ability to thoroughly clean the concrete and steel. For example, it may be necessary to use needle scaling (a small pneumatic impact device) and wire brushing instead of sandblasting.

Supplemental steel may be needed when existing reinforcing steel is severely deteriorated, or if reinforcing steel is not present in repair areas. Exposed existing reinforcing and other embedded steel elements can be cleaned, primed, and painted with a corrosion-inhibiting coating. The patching material should be reinforced

and mechanically attached to the existing concrete. Reinforcement materials used in repairs most often include mild steel, epoxy-coated steel, or stainless steel, depending on existing conditions.

### Formwork and Molds

Special formwork is needed to recreate ornamental concrete features—which may be complex, in high relief, or architecturally detailed—and to provide special surface finishes such as wood form board textures. Construction of the formwork itself requires particular skill and craftsmanship. Reusable forms can be used for concrete ornamentation that is repeated across a building facade, or precast concrete elements may be used to replace missing or unrepairable architectural features. Formwork for ornamental concrete is often created using a four-step process: a casting of the original concrete is taken; a plaster replica of the unit is prepared; a mold or form is made from the plaster replica; and a new concrete unit is cast. Custom formwork and molds are often the work of specialty companies, such as precasters and cast stone fabricators.

The process of forming architectural features or special surface textures is particularly challenging if early age stripping (removal of formwork early in the concrete curing process) is needed to perform surface treatment on the concrete. Timing for formwork removal is related to strength gain, which in turn is partly dependent on temperature and weather conditions. Early age removal of formwork in highly detailed concrete can lead to damage of the new concrete that has not yet gained sufficient strength through curing.

### Selection of Repair Materials and Mix Design

Selection and design of proper repair materials is a critical component of the repair project. This process requires evaluation of the performance, characteristics, and limitations of the repair materials, and may involve laboratory testing of proposed materials and trial repairs. The materials should be selected to address the specific type of repair required and to be compatible with special characteristics of the original concrete. Some modern repair materials are designed to have a high compressive strength and to be impermeable. Even though inherently durable, these newer materials may not be appropriate for use in repairing a low strength historic concrete.

The concrete's durability, or resistance to deterioration, and the materials and methods selected for repair depend on its composition, design, and quality of workmanship. In most cases, a mix design for durable replacement concrete should use materials similar to those of the original concrete mix. Prepackaged materials are often not appropriate for repair of historic concrete. The concrete patching material can be air entrained or polymer-modified if subject to exterior exposure, and should incorporate an appropriate selection of aggregate and cement type, and proper water content and water



Figure 18. (a) Exposed aggregate precast concrete is sounded with a hammer to detect areas of deterioration. Corrosion of the exposed reinforcing steel bar has led to spalling of the adjacent concrete. (b) Samples of aggregate considered for use in repair concrete are compared to the original concrete materials in terms of size, color, texture, and reflectance. (c) Various sample panels are made using the selected concrete repair mix design for comparison to the original concrete on the building, and the mix design is adjusted based on review of the samples. (d) After removal of the spall, the concrete surface is prepared for installation of a formed patch. (e) Prior to placement of the concrete, a retarding agent is brush-applied to the inside face of the formwork to slow curing at the surface. After the concrete is partially cured, the forms are removed and the surface of the concrete is rubbed to remove some of the paste and expose the aggregate to match the original concrete.

to cement ratio. Some admixtures, including polymer modifiers, may change the appearance of the concrete mix. Design of the concrete patching material should address characteristics required for durability, workability, strength gain, compressive strength, and other performance attributes. During installation of the repair, skilled workmanship is required to ensure proper mixing procedures, placement, consolidation, and curing.

### *Matching and Repair Techniques for Historic Concrete*

Repair measures should be selected that retain as much of the original material as possible, while providing for removal of an adequate amount of deteriorated concrete to provide a sound substrate for a durable repair. The installed repair must visually match the existing concrete as closely as possible and should be similar in other aspects such as compressive strength, permeability, and other characteristics important in the mix design of the concrete (Fig. 18).

Understanding the original construction techniques often provides opportunities in the design of repairs. For example, joints between the new and old concrete can be hidden in changes in surface profile and cold joints. The required patching mix for the concrete to be used in the repair will likely need to be specially designed to replicate the appearance of the adjacent historic concrete. A high level of craftsmanship is required for finishing of historic concrete, in particular to create the sometimes inconsistent finish and variation in the original concrete in contrast to the more even appearance required for most non-historic repairs.

To match the various characteristics of the original concrete, trial mixes should be developed. These mixes need to take into account the types and colors of aggregates and paste present in the original concrete. Different mixes may be needed because of variations in the appearance and composition of the historic concrete. The trials should utilize different forming and finishing techniques to achieve the best possible match to the original concrete. Initial trials should first take place on site but off the structure. The mix designs providing the best match are then installed as trial repairs on the structure, and assessed after they have cured.

Achieving compatibility between repair work and original concrete may be difficult, especially given the variability often present in historic concrete materials and finishes. Formed rather than trowel-applied patch repairs are recommended for durability, as forming permits better ranges of mix ingredients (such as coarse aggregates) and improved consolidation as compared to trowel-applied repairs. Parge coatings usually are not recommended as they do not provide as durable repair as formed concrete. However, in some cases parge coatings may be appropriate to match an original parged surface treatment. Proper placement and finishing of the repair are important to obtain a match with the original concrete. To minimize problems associated with rapid curing of concrete, such as surface cracking, it is important to use proper curing methods and to allow for sufficient time.

Hairline cracks that show no sign of increasing in size may often be left unrepaired. The width of the crack and the amount of movement usually limits the selection of crack repair techniques that are available. Although it is difficult to determine whether cracks are moving or non-moving, and therefore most cracks



should be assumed to be moving, it is possible to repair non-moving cracks by installation of a cementitious repair mortar matching the adjacent concrete. It is generally desirable not to widen cracks prior to the mortar application. Repair mortar containing sand in the mix may be used for wider cracks; unsanded repair mortar may be used for narrower cracks.

When it is desirable to re-establish the structural integrity of a concrete structure involving dormant cracks, epoxy injection repair has proven to be an effective procedure. Such a repair is made by first sealing the crack on both sides of a wall or structural member with epoxy, polyester, wax, tape, or cement slurry, and then injecting epoxy through small holes or ports drilled in the concrete. Once the epoxy in the crack has hardened, the surface sealing material may be removed; however, this type of repair is usually quite apparent. Although it may be possible to inject epoxy without leaving noticeable residue, this process is difficult and, in general, the use of epoxy repairs in visible areas of concrete on historic structures is not recommended.

Active structural cracks (which move as loads are added or removed) and thermal cracks (which move as temperatures fluctuate) must be repaired in a manner that will accommodate the anticipated movement. In some more extreme cases, expansion joints may have to be introduced before crack repairs are undertaken. Active cracks may be filled with sealants that will adhere to the sides of the cracks and will compress or expand during crack movement. The design, detailing, and execution of sealant repairs require considerable attention, or they will detract from the appearance of the historic building. The routing and cleaning of a crack, and installation of an elastomeric sealant to prevent water penetration, is used to address cracks where movement is anticipated. However, unless located in a concealed area of the concrete, this technique is often not acceptable for historic structures because the repair will be visually intrusive (Fig. 19). Other approaches, such as installation of a cementitious crack repair, may need to be considered even though this type of repair may be less effective or have a shorter service life than a sealant repair.

### Replacement

If specific components of historic concrete structures are beyond repair, replacement components can be cast to match historic ones. Replacement of original concrete should be carefully considered and viewed as a method of last resort. In some cases, such as for repeated ornamental units, it may be more cost-effective to fabricate precast concrete units to replace missing elements. The forms created for precast or cast-in-place units can then be used again during future repair projects.

Careful mix formulation, placement, and finishing are required to ensure that replacement concrete units will match the historic concrete. There is often a tendency to make replacement concrete more consistent in appearance than the original concrete. The consistency can be in stark contrast with the variability of the original concrete



Figure 19. A high-speed grinder is used to widen a crack in preparation for installation of a sealant. This process is called "routing." After the crack is prepared, the sealant is installed to prevent moisture infiltration through the crack. Although sealant repairs can provide a durable, watertight repair for moving cracks, they tend to be very visible.

due to original construction techniques, architectural design, or differential exposure to weather. Trial repairs and mock-ups are used to evaluate the proposed replacement concrete work and to refine construction techniques (Fig 20).

### Protection Systems

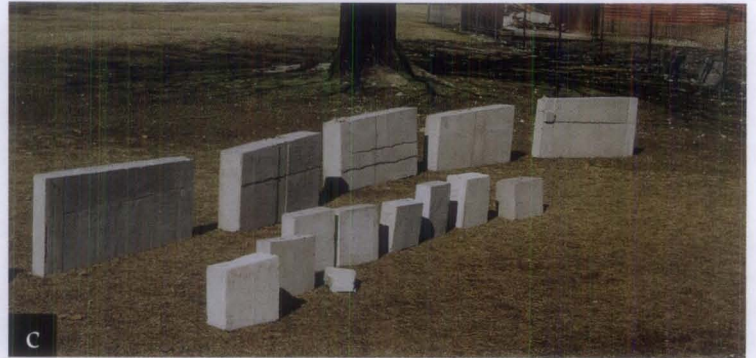
**Coatings and Penetrating Sealers.** Protection systems such as a penetrating sealers or film forming coating are often used with non-historic structures to protect the concrete and increase the length of the service life of concrete repairs. However, film-forming coatings are often inappropriate for use on a historic structure, unless the structure was coated historically. Film-forming coatings will often change the color and appearance of a surface, and higher build coatings can also mask architectural finishes and ornamental details. For example, the application of a coating on concrete having a formboard finish may hide the wood texture of the surface. Pigmented film-forming coatings are also typically not appropriate for use over exposed aggregate concrete, where the uncoated exposed surface contributes significantly to the historic character of



a



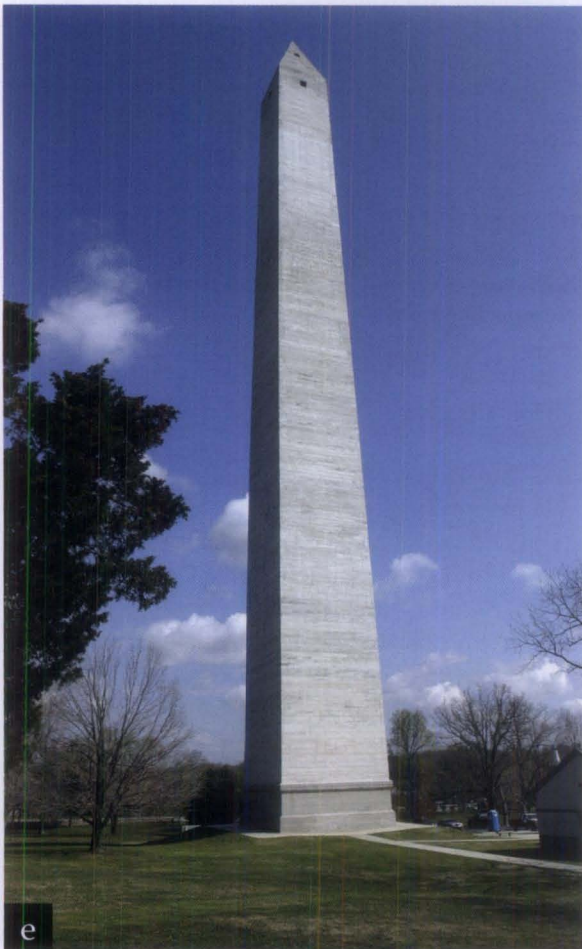
b



c



d



e

Figure 20. (a) The Jefferson Davis Memorial in Fairview, Kentucky, constructed from 1917–1924, is 351 feet tall and constructed of unreinforced concrete. The walls of the memorial are 8 feet thick at the base and 2 feet thick at the top of the wall. Access to the monument for investigation was provided by rappelling techniques, while ground supported and suspended scaffolding was used to access the exterior during repairs. (b) The concrete was severely deteriorated at isolated locations, with spalling and damage from cyclic freezing and thawing of entrapped water. In addition, previous repairs were at the end of their service life and removal of deteriorated concrete and failed previous repairs was required. Light duty chipping hammers were used to avoid damage to adjacent material when removing deteriorated concrete to the level of sound concrete. (c) Field samples were performed to match the color, finish, and texture of the original concrete. A challenge in matching of historic concrete is achieving variability of appearance. (d) The completed surface after repairs exhibits intentional variability of the concrete surface to match the appearance of the original concrete. Some formwork imperfections that would normally be removed by finishing were intentionally left in place, to replicate the highly variable finish of the original concrete. (e) The Jefferson Davis Memorial after completion of repairs in 2004. Photo e: Joseph Lenzi, Senler, Campbell & Associates, Inc.

concrete. In cases where the color of a substrate needs to be changed, such as to modify the appearance of existing repairs, an alternative to pigmented film-forming coatings is the use of pigmented stains.

Many proprietary clear, penetrating sealers are currently available to protect concrete substrates. These products render fine cracks and pores within the concrete hydrophobic; however, they do not bridge or fill cracks. Clear sealers may change the appearance of the concrete in that treated areas become more visible after rain in contrast to the more absorptive areas of original concrete. Once applied, penetrating sealers cannot be effectively removed and are therefore considered irreversible. They should not be used on historic concrete without thorough prior consideration. However, clear penetrating sealers provide an important means of protection for historic concrete that is not of good quality and can help to avoid more extensive future repairs or replacement. Thus they are sometimes appropriate for use on historic concrete. Once applied, these sealers will require periodic re-application.

Waterproofing membranes are systems used to protect concrete surfaces such as roofs, terraces, plazas, or balconies, as well as surfaces below grade. Systems range from coal tar pitch membranes used on older buildings, to asphalt or urethane-based systems. On historic buildings, membrane systems are typically used only on surfaces that were originally protected by a similar system and surfaces that are not visible from grade. Waterproofing membranes may be covered by roofing, paving, or other architectural finishes.

Laboratory and field testing is recommended prior to application of a protection system or treatment on any concrete structure; testing is even more critical for historic structures because many such treatments are not reversible. As with other repairs, trial samples are important to evaluate the effectiveness of the treatment and to determine whether it will harm the concrete or affect its appearance.

**Cathodic Protection.** Corrosion is an electrochemical process in which electrons flow between cathodic (positively charged) and anodic (negatively charged) areas on a metal surface; corrosion occurs at the anodes. Cathodic protection is a technique used to control the corrosion of metal by making the whole metal surface the cathode of an electrochemical cell. This technique is used to protect metal structures from corrosion and is also sometimes used to protect steel reinforcement embedded in concrete. For reinforced concrete, cathodic protection is typically accomplished by connecting an auxiliary anode to the reinforcing so that the entire reinforcing bar becomes a cathode. In sacrificial anode (passive) systems, current flows naturally by galvanic action between the less noble anode (such as zinc) and the cathode. In impressed-current (active) systems, current is impressed between an inert anode (such as titanium) and the cathode. Cathodic protection is intended to reduce the rate of corrosion of embedded steel in concrete, which in turn reduces overall deterioration. Protecting embedded steel from corrosion helps to prevent concrete cracking and spalling.

Impressed-current cathodic protection is the most effective means of mitigating steel corrosion and has been used in practical structural applications since the 1970s. However, impressed-current cathodic protection systems are typically the most costly to install and require substantial ongoing monitoring, adjustment, and maintenance to ensure a proper voltage output (protection current) over time. Sacrificial anode cathodic protection dates back to the 1800s, when the hulls of ships were protected using this technology. Today many industries utilize the concept of sacrificial anode cathodic protection for the protection of steel exposed to corrosive environments. It is less costly than an impressed-current system, but is somewhat less effective and requires reapplication of the anode when it becomes depleted.

**Re-alkalization.** Another technique currently available to protect concrete is realkalization, which is a process to restore the alkalinity of carbonated concrete. The treatment involves soaking the concrete with an alkaline solution, in some cases forcing it into the concrete to the level of the reinforcing steel by passage of direct current. These actions increase the alkalinity of the concrete around the reinforcement, thus restoring the protective alkaline environment for the reinforcement. Like impressed-current cathodic protection methods, it is costly. Other corrosion methods are also available but have a somewhat shorter history of use.

Careful evaluation of existing conditions, the causes and nature of distress, and environmental factors is essential before a protection method is selected and implemented. Not every protection system will be effective on each structure. In addition, the level of intrusion caused by the protection system must be carefully evaluated before it is used on a historic concrete structure.

## Summary

In the United States, concrete has been a popular construction material since the late nineteenth century and recently has gained greater recognition as a historic material. Preservation of historic concrete requires a thorough understanding of the causes and types of deterioration, as well as of repair and replacement materials and methods. It is important that adequate time is allotted during the planning phase of a project to provide for trial repairs and mock-ups in order to evaluate the effectiveness and aesthetics of the repairs. Careful design is essential and, as with other preservation efforts, the skill of those performing the work is critical to the success of the repairs. The successful repair of many historic concrete structures in recent years demonstrates that the techniques and materials now available can extend the life of such structures and help ensure their preservation.

## Selected Reading

- American Concrete Institute. *Guide for Making a Condition Survey of Concrete in Service*. ACI Committee 201, ACI 201.1R-92.
- American Concrete Institute. *Guide to Evaluation of Concrete Structures before Rehabilitation*. ACI Committee 364, ACI 364.1R-07.
- American Concrete Institute. *Concrete Repair Guide*. ACI Committee 546, ACI 546R-04.
- American Concrete Institute. *Guide for Evaluation of Existing Concrete Buildings*. ACI Committee 437, ACI 437R-03.
- Childe, H.L. *Manufacture and Uses of Concrete Products and Cast Stone*. London: Concrete Publications Limited, 1930.
- Collins, Peter. *Concrete: The Vision of a New Architecture*. New York, New York: Faber and Faber, 1959.
- Cowden, Adrienne B., comp. *Historic Concrete: An Annotated Bibliography*. Washington, D.C.: National Park Service, 1993.
- Komandant, August E. *Contemporary Concrete Structures*. New York, New York: McGraw Hill, 1972.
- Erlemann, Gustav G. "Steel Reinforcing Bar Specification in Old Structures." *Concrete International*, April 1999, 49–50.
- Federal Highway Administration. *Guide to Nondestructive Testing of Concrete*. FHWA Publication Number FHWA-SA-97-105.
- Gaudette, Paul E. "Special Considerations in Repair of Historic Concrete." *Concrete Repair Bulletin*, January/February 2000, 12–13.
- Jester, Thomas C., ed. *Twentieth Century Building Materials*. New York, New York: McGraw-Hill, 1995.
- Johnson, Arne P, and Seung Kyoung Lee. "Protection Methods for Historic Concrete at Soldier Field." *Preserve and Play: Preserving Historic Recreation and Entertainment Sites*. Washington, D.C.: Historic Preservation Education Foundation, National Council for Preservation Education, and National Park Service, 2006.
- Macdonald, Susan, ed. *Concrete: Building Pathology*. Osney Mead, Oxford, U.K.: Blackwell Science, 2003.
- McGovern, Martin S. "A Clear View of Sealers." *Concrete Construction*, January 2000, 53–58.
- Morton, W. Brown III, Gary L. Hume, Kay D. Weeks, H. Ward Jandl, and Anne E. Grimmer. *The Secretary of the Interior's Standards for Rehabilitation & Illustrated Guidelines for Rehabilitating Historic Buildings*. Washington, D.C.: National Park Service, 1983, reprinted 1997.
- "Repairing Cracks." *Concrete Repair Digest*, August/September 1992, 160–164. Condensed from ACI document 224.1R-93.
- Slaton, Deborah. "Cleaning Historic Concrete." *Concrete Repair Bulletin*, January/February 2000, 14–15.

## Acknowledgements

Paul Gaudette is an engineer with Wiss, Janney, Elstner Associates, Inc., in Chicago, Illinois. Deborah Slaton is an architectural conservator with Wiss, Janney, Elstner Associates, Inc., in Northbrook, Illinois. All photographs by Paul Gaudette unless otherwise stated. Front cover image: Kyle Normandin, Wiss, Janney, Elstner Associates, Inc.

The authors wish to thank William Bing Coney, author of the first edition of this preservation brief, who served as a peer reviewer for the current edition. In addition, the authors gratefully acknowledge the assistance of the following individuals as peer reviewers of this brief: Arne Johnson and Una Gilmartin, Wiss, Janney, Elstner Associates, Inc.; Robert Joyce, Quality Restorations, Inc.; Susan Macdonald, New South Wales Heritage Office; Miles T. Murray, Restruction Corporation; and Jack Pyburn, OJP/Architect, Inc. Anne E. Grimmer, Chad Randl, and former staff Sharon C. Park, FAIA, of the Technical Preservation Services, National Park Service, offered valuable comments during development of the brief. Charles E. Fisher of the National Park Service was the technical editor for this publication project.

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. Comments about this publication should be addressed to: Charles E. Fisher, Technical Preservation Publications Program Manager, Technical Preservation Services—2255, National Park Service, 1849 C Street, NW, Washington, DC 20240. This publication is not copyrighted and can be reproduced without penalty. Normal procedures for credit to the authors and the National Park Service should be provided. The photographs used in this publication may not be used to illustrate other publications without permission of the owners. For more information about the programs of the National Park Service's Technical Preservation Services see our website at <http://www.nps.gov/history/hps/tps.htm>

ISBN: 978-0-16-078946-5

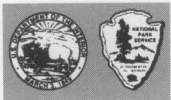
U.S. Government Printing Office Stock Number: 024-005-01253-2

2007

# 16 PRESERVATION BRIEFS

## The Use of Substitute Materials on Historic Building Exteriors

Sharon C. Park, AIA



U.S. Department of the Interior  
National Park Service  
Cultural Resources  
Heritage Preservation Services



The Secretary of the Interior's *Standards for Rehabilitation* require that "deteriorated architectural features be repaired rather than replaced, wherever possible. In the event that replacement is necessary, the new material should match the material being replaced in composition, design, color, texture, and other visual properties." Substitute materials should be used only on a limited basis and only when they will match the appearance and general properties of the historic material and will not damage the historic resource.

### Introduction

When deteriorated, damaged, or lost features of a historic building need repair or replacement, it is almost always best to use historic materials. In limited circumstances substitute materials that imitate historic materials may be used if the appearance and properties of the historic materials can be matched closely and no damage to the remaining historic fabric will result.

Great care must be taken if substitute materials are used on the exteriors of historic buildings. Ultra-violet light, moisture penetration behind joints, and stresses caused by changing temperatures can greatly impair the performance of substitute materials over time. Only after consideration of all options, in consultation with qualified professionals, experienced fabricators and contractors, and development of carefully written specifications should this work be undertaken.

The practice of using substitute materials in architecture is not new, yet it continues to pose practical problems and to raise philosophical questions. On the practical level the inappropriate choice or improper installation of substitute materials can cause a radical change in a building's appearance and can cause extensive physical damage over time. On the more philosophical level, the wholesale use of substitute materials can raise questions concerning the integrity of historic buildings largely comprised of new materials. In both cases the integrity of the historic resource can be destroyed.

Some preservationists advocate that substitute materials should be avoided in all but the most limited cases. The fact is, however, that substitute materials are being used more frequently than ever in preservation projects, and in many cases with positive results. They can be cost-effective, can permit

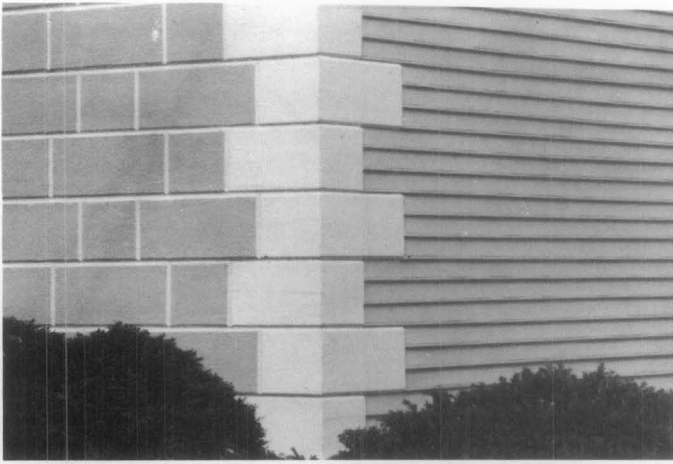
the accurate visual duplication of historic materials, and last a reasonable time. Growing evidence indicates that with proper planning, careful specifications and supervision, substitute materials can be used successfully in the process of restoring the visual appearance of historic resources.

This Brief provides general guidance on the use of substitute materials on the exteriors of historic buildings. While substitute materials are frequently used on interiors, these applications are not subject to weathering and moisture penetration, and will not be discussed in this Brief. Given the general nature of this publication, specifications for substitute materials are not provided. The guidance provided should not be used in place of consultations with qualified professionals. This Brief includes a discussion of when to use substitute materials, cautions regarding their expected performance, and descriptions of several substitute materials, their advantages and disadvantages. This review of materials is by no means comprehensive, and attitudes and findings will change as technology develops.

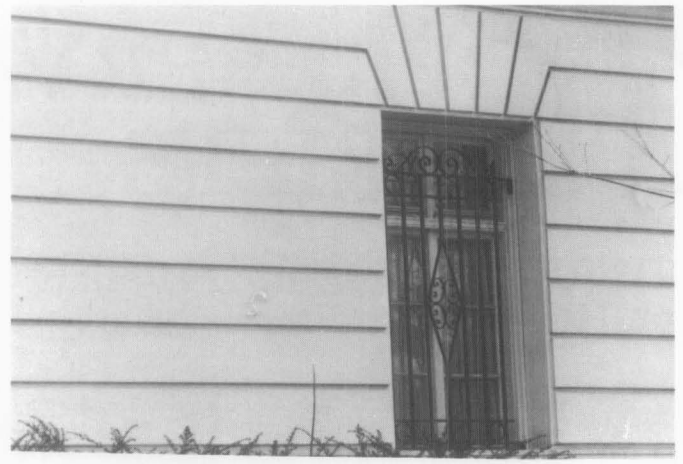
### Historical Use of Substitute Materials

The tradition of using cheaper and more common materials in imitation of more expensive and less available materials is a long one. George Washington, for example, used wood painted with sand-impregnated paint at Mount Vernon to imitate cut ashlar stone. This technique along with scoring stucco into block patterns was fairly common in colonial America to imitate stone (see illus. 1, 2).

Molded or cast masonry substitutes, such as dry-tamp cast stone and poured concrete, became popular in place of quarried stone during the 19th century. These masonry units were fabricated locally, avoiding



*Illus. 1. An early 18th-century technique for imitating carved or quarried stone was the use of sand-impregnated paint applied to wood. The facade stones and quoins are of wood. The Lindens (1754), Washington, D.C. Photo: Sharon C. Park, AIA.*



*Illus. 2. Stucco has for many centuries represented a number of building materials. Seen here is the ground floor of a Beaux Arts mansion, circa 1900, which represents a finely laid stone foundation wall executed in scored stucco. Photo: Sharon C. Park, AIA.*



*Illus. 3. Casting concrete to represent quarried stone was a popular late 19th-century technique seen in this circa 1910 mail-order house. While most components were delivered by rail, the foundations and exterior masonry were completed by local craftsmen. Photo: Sharon C. Park, AIA.*



*Illus. 4. The 19th-century also produced a variety of metal products used in imitation of other materials. In this case, the entire exterior of the Long Island Safety Deposit Company is cast-iron representing stone. Photo: Becket Logan, Friends of Cast Iron Architecture.*

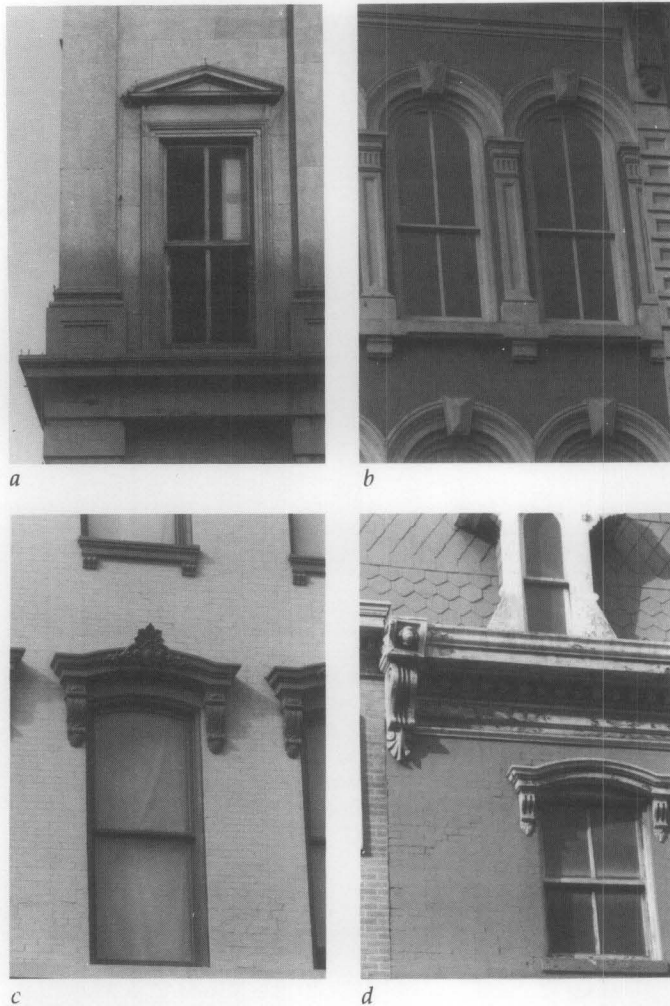
expensive quarrying and shipping costs, and were versatile in representing either ornately carved blocks, plain wall stones or rough cut textured surfaces. The end result depended on the type of patterned or textured mold used and was particularly popular in conjunction with mail order houses (see illus. 3). Later, panels of cementitious perma-stone or formstone and less expensive asphalt and sheet metal panels were used to imitate brick or stone.

Metal (cast, stamped, or brake-formed) was used for storefronts, canopies, railings, and other features, such as galvanized metal cornices substituting for wood or stone, stamped metal panels for Spanish clay roofing tiles, and cast-iron column capitals and even entire building fronts in imitation of building stone (see illus. no. 4).

Terra cotta, a molded fired clay product, was itself a substitute material and was very popular in the late 19th and early 20th centuries. It simulated the ap-

pearance of intricately carved stonework, which was expensive and time-consuming to produce. Terra cotta could be glazed to imitate a variety of natural stones, from brownstones to limestones, or could be colored for a polychrome effect.

Nineteenth century technology made a variety of materials readily available that not only were able to imitate more expensive materials but were also cheaper to fabricate and easier to use. Throughout the century, imitative materials continued to evolve. For example, ornamental window hoods were originally made of wood or carved stone. In an effort to find a cheaper substitute for carved stone and to speed fabrication time, cast stone, an early form of concrete, or cast-iron hoods often replaced stone. Toward the end of the century, even less expensive sheet metal hoods, imitating stone, also came into widespread use. All of these materials, stone, cast stone, cast-iron, and various pressed metals were in



*Illus. 5. The four historic examples of various window hoods shown are: (a) stone; (b) cast stone; (c) cast-iron; and (d) sheet metal. The criteria for selecting substitute materials today (availability, quality, delivery dates, cost) are not much different from the past. Photo: Sharon C. Park, AIA.*

## When to Consider Using Substitute Materials in Preservation Projects

Because the overzealous use of substitute materials can greatly impair the historic character of a historic structure, all preservation options should be explored thoroughly before substitute materials are used. It is important to remember that the purpose of repairing damaged features and of replacing lost and irreparably damaged ones is both to match visually what was there and to cause no further deterioration. For these reasons it is not appropriate to cover up historic materials with synthetic materials that will alter the appearance, proportions and details of a historic building and that will conceal future deterioration (see illus. 6).

Some materials have been used successfully for the repair of damaged features such as epoxies for wood infilling, cementitious patching for sandstone repairs, or plastic stone for masonry repairs. Repairs are preferable to replacement whether or not the repairs are in kind or with a synthetic substitute material (see illus. 7).

In general, four circumstances warrant the consideration of substitute materials: 1) the unavailability of historic materials; 2) the unavailability of skilled craftsmen; 3) inherent flaws in the original materials; and 4) code-required changes (which in many cases can be extremely destructive of historic resources).

Cost may or may not be a determining factor in considering the use of substitute materials. Depending on the area of the country, the amount of material needed, and the projected life of less durable substitute materials, it may be cheaper in the long run to use the original material, even though it may be harder to find. Due to many early failures of substitute materials, some preservationist are looking abroad to find materials (especially stone) that match the historic materials in an effort to restore historic

production at the same time and were selected on the basis of the availability of materials and local craftsmanship, as well as durability and cost (see illus. 5). The criteria for selection today are not much different.

Many of the materials used historically to imitate other materials are still available. These are often referred to as the traditional materials: wood, cast stone, concrete, terra cotta and cast metals. In the last few decades, however, and partly as a result of the historic preservation movement, new families of synthetic materials, such as fiberglass, acrylic polymers, and epoxy resins, have been developed and are being used as substitute materials in construction. In some respects these newer products (often referred to as high tech materials) show great promise; in others, they are less satisfactory, since they are often difficult to integrate physically with the porous historic materials and may be too new to have established solid performance records.



*Illus. 6. Substitute materials should never be considered as a cosmetic cover-up for they can cause great physical damage and can alter the appearance of historic buildings. For example, a fiberglass coating was used at Ranchos de Taos, NM, in place of the historic adobe coating which had deteriorated. The waterproof coating sealed moisture in the walls and caused the spalling shown. It was subsequently removed and the walls were properly repaired with adobe. Photo: Lee H. Nelson, FAIA.*



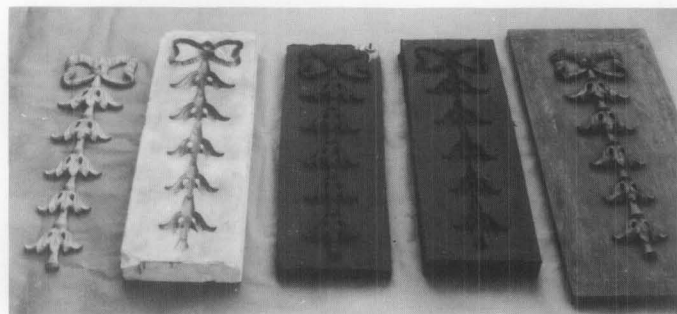
*Illus. 7. Whenever possible, historic materials should be repaired rather than replaced. Epoxy, a synthetic resin, has been used to repair the wood window frame and sill at the Auditors Building (1878) Washington, DC. The cured resin is white in this photo and will be primed and painted. Photo: Lee H. Nelson, FAIA.*



*Illus. 8. Even when materials are not locally available, it may be possible and cost effective to find sources elsewhere. For example, the local sandstone was no longer available for the restoration of the New York Shakespeare Festival Public Theater. The deteriorated sandstone window hoods, were replaced with stone from Germany that closely matched the color and texture of the historic sandstone. Photo: John G. Waite.*



*Illus. 9. Simple solutions should not be overlooked when materials are no longer available. In the case of the Morse-Libby Mansion (1859), Portland, ME, the deteriorated brownstone porch beam was replaced with a carved wooden beam painted with sand impregnated paint. Photo: Stephen Sewall.*



*Illus. 10. The use of substitute materials is not necessarily cheaper or easier than using the original materials. The complex process of fabricating the polyester bronze reproduction pieces of the gilded wood molding for the clockcase at Independence Hall required talented artisans and substantial mold-making time. From left to right is the final molded polyester bronze detail; the plaster casting mold; the positive and negative interim neoprene rubber molds; and the expertly carved wooden master. Photo: Courtesy of Independence National Historical Park.*

buildings accurately and to avoid many of the uncertainties that come with the use of substitute materials.

**1. The unavailability of the historic material.** The most common reason for considering substitute materials is the difficulty in finding a good match for the historic material (particularly a problem for masonry materials where the color and texture are derived from the material itself). This may be due to the actual unavailability of the material or to protracted delivery dates. For example, the local quarry that supplied the sandstone for a building may no longer be in operation. All efforts should be made to locate another quarry that could supply a satisfactory match (see illus. 8). If this approach fails, substitute materials such as dry-tamp cast stone or textured precast concrete may be a suitable substitute if care is taken to ensure that the detail, color and texture of the original stone are matched. In some cases, it may be possible to use a sand-impregnated paint on wood

as a replacement section, achieved using readily available traditional materials, conventional tools and work skills. (see illus. 9). Simple solutions should not be overlooked.

**2. The unavailability of historic craft techniques and lack of skilled artisans.** These two reasons complicate any preservation or rehabilitation project. This is particularly true for intricate ornamental work, such as carved wood, carved stone, wrought iron, cast iron, or molded terra cotta. However, a number of stone and wood cutters now employ sophisticated carving machines, some even computerized. It is also possible to cast substitute replacement pieces using



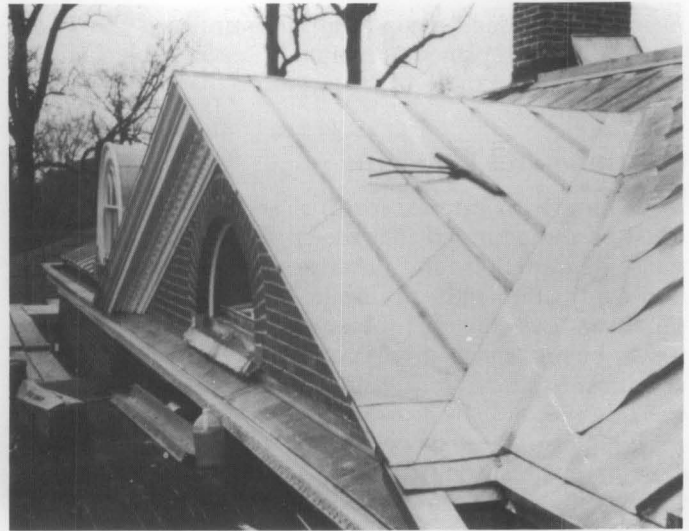


*Illus. 11. The unavailability of historic craft techniques is another reason to consider substitute materials. The original first floor cast iron front of the Grand Opera House, Wilmington, DE, was missing; the expeditious reproduction in cast aluminum was possible because artisans working in this medium were available. Photo: John G. Waite.*

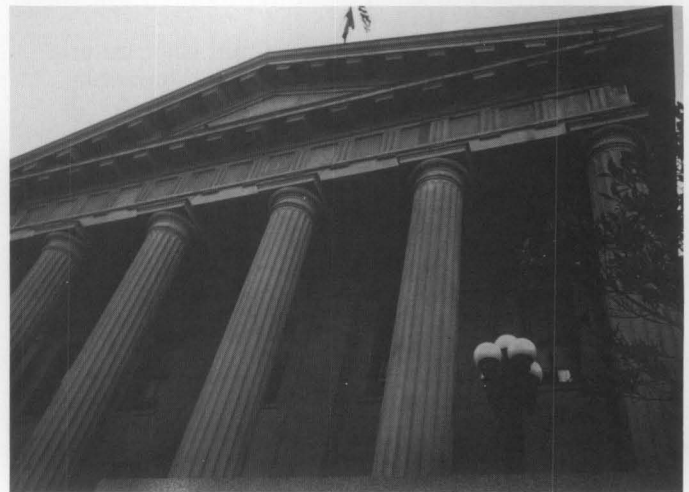
aluminum, cast stone, fiberglass, polymer concretes, glass fiber reinforced concretes and terra cotta. Mold making and casting takes skill and craftsmen who can undertake this work are available. (see illus. 10, 11). Efforts should always be made, prior to replacement, to seek out artisans who might be able to repair ornamental elements and thereby save the historic features in place.

**3. Poor original building materials.** Some historic building materials were of inherently poor quality or their modern counterparts are inferior. In addition, some materials were naturally incompatible with other materials on the building, causing staining or galvanic corrosion. Examples of poor quality materials were the very soft sandstones which eroded quickly. An example of poor quality modern replacement material is the tin coated steel roofing which is much less durable than the historic tin or terne iron which is no longer available. In some cases, more durable natural stones or precast concrete might be available as substitutes for the soft stones and modern terne-coated stainless steel or lead-coated copper might produce a more durable yet visually compatible replacement roofing (see illus. 12).

**4. Code-related changes.** Sometimes referred to as life and safety codes, building codes often require changes to historic buildings. Many cities in earthquake zones, for example, have laws requiring that overhanging masonry parapets and cornices, or freestanding urns or finials be securely reanchored to new structural frames or be removed completely. In some cases, it may be acceptable to replace these heavy historic elements with light replicas (see illus. 13). In other cases, the extent of historic fabric removed may be so great as to diminish the integrity of the resource. This could affect the significance of the structure and jeopardize National Register status. In addition, removal of repairable historic materials could result in loss of Federal tax credits for rehabilitation. Department of the Interior regulations make



*Illus. 12. Substitute materials may be considered when the original materials have not performed well. For example, early sheet metals used for roofing, such as tinplate, were reasonably durable, but the modern equivalent, terne-coated steel, is subject to corrosion once the thin tin plating is damaged. Terne-coated stainless steel or lead-coated copper (shown here) are now used as substitutes. Photo: John G. Waite.*



*Illus. 13. Code-related changes are of concern in historic preservation projects because the integrity of the historic resource may be irretrievably affected. In the case of the Old San Francisco Mint, the fiberglass cornice was used to bring the building into seismic conformance. The original cornice was deteriorated, and the replacement (1982) was limited to the projecting pediment. The historic stone fascia was retained as were the stone columns. The limited replacement of deteriorated material did not jeopardize the integrity of the building. Photo: Walter M. Sontheimer.*

clear that the Secretary of the Interior's Standards for Rehabilitation take precedence over other regulations and codes in determining whether a project is consistent with the historic character of the building undergoing rehabilitation.

Two secondary reasons for considering the use of substitute materials are their lighter weight and for some materials, a reduced need of maintenance. These reasons can become important if there is a

need to keep dead loads to a minimum or if the feature being replaced is relatively inaccessible for routine maintenance.

## Cautions and Concerns

In dealing with exterior features and materials, it must be remembered that moisture penetration, ultra-violet degradation, and differing thermal expansion and contraction rates of dissimilar materials make any repair or replacement problematic. To ensure that a repair or replacement will perform well over time, it is critical to understand fully the properties of both the original and the substitute materials, to install replacement materials correctly, to assess their impact on adjacent historic materials, and to have reasonable expectations of future performance.

Many high tech materials are too new to have been tested thoroughly. The differences in vapor permeability between some synthetic materials and the historic materials have in some cases caused unexpected further deterioration. It is therefore difficult to recommend substitute materials if the historic materials are still available. As previously mentioned, consideration should always be given first to using traditional materials and methods of repair or replacement before accepting unproven techniques, materials or applications.

Substitute materials must meet three basic criteria before being considered: they must be compatible with the historic materials in appearance; their physical properties must be similar to those of the historic materials, or be installed in a manner that tolerates differences; and they must meet certain basic performance expectations over an extended period of time.

### Matching the Appearance of the Historic Materials

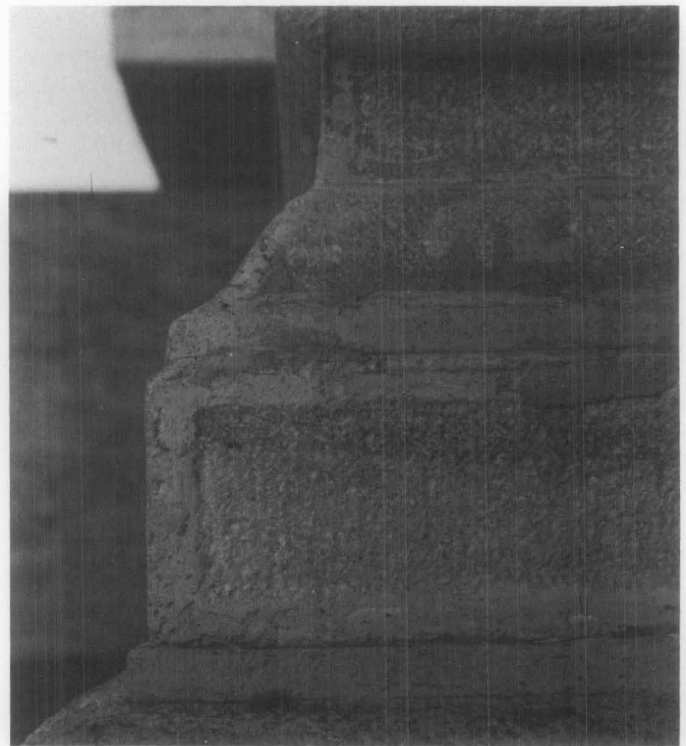
In order to provide an appearance that is compatible with the historic material, the new material should match the details and craftsmanship of the original as well as the color, surface texture, surface reflectivity and finish of the original material (see illus. 14). The closer an element is to the viewer, the more closely the material and craftsmanship must match the original.

Matching the color and surface texture of the historic material with a substitute material is normally difficult. To enhance the chances of a good match, it is advisable to clean a portion of the building where new materials are to be used. If pigments are to be added to the substitute material, a specialist should determine the formulation of the mix, the natural aggregates and the types of pigments to be used. As all exposed material is subject to ultra-violet degradation, if possible, samples of the new materials made during the early planning phases should be tested or allowed to weather over several seasons to test for color stability.

Fabricators should supply a sufficient number of samples to permit on-site comparison of color, texture, detailing, and other critical qualities (see illus. 15, 16). In situations where there are subtle variations in color and texture within the original materials, the



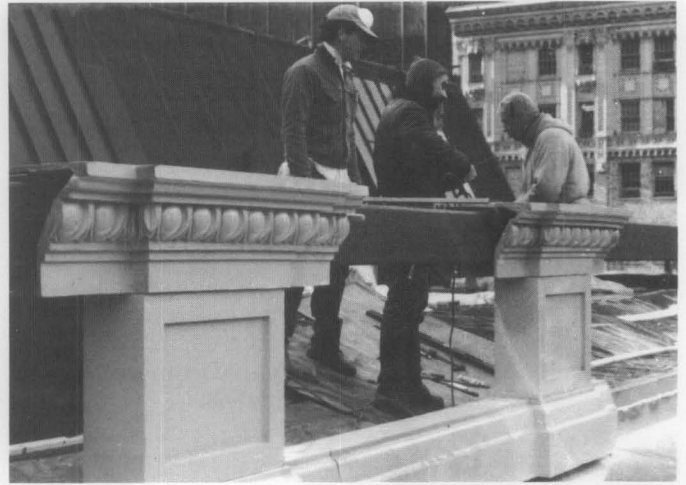
*Illus. 14. The visual qualities of the historic feature must be matched when using substitute materials. In this illustration, the lighter weight mineral fiber cement shingles used to replace the deteriorated historic slate roof were detailed to match the color, size, shape and pattern of the original roofing and the historic snow birds were reattached. Photo: Sharon C. Park, AIA.*



*Illus. 15. Poor quality workmanship can be avoided. In this example, the crudely cast concrete entrance pier (shown) did not match the visual qualities of the remaining historic sandstone (not shown). The aggregate is too large and exposed; the casting is not crisp; the banded tooling edges are not articulated; and the color is too pale. Photo: Sharon C. Park, AIA.*



*Illus. 16. The good quality substitute materials shown here do match the historic sandstone in color, texture, tooling and surface details. Dry-tamp cast stone was used to match the red sandstone that was no longer available. The reconstructed first floor incorporated both historic and substitute materials. Sufficient molds were made to avoid the problem of detecting the substitutes by their uniformity. Photo: Sharon C. Park, AIA.*



*Illus. 18. Substitute materials must be properly installed to allow for expansion, contraction, and structural security. The new balustrade (a polymer concrete modified with glass fibers) at Carnegie Hall, New York City, was installed with steel structural supports to allow window-washing equipment to be suspended securely. In addition, the formulation of this predominantly epoxy material allowed for the natural expansion and contraction within the predesigned joints. Photo: Courtesy of MJM Studios.*



*Illus. 17. Care must be taken to ensure that the replacement materials will work within a predesigned system. At the Norris Museum, Yellowstone National Park, the 12-inch diameter log rafters, part of an intricate truss system, had rotted at the inner core from the exposed ends back to a depth of 48 inches. The exterior wooden shells remained intact. Fiberglass rods (left photo) and specially formulated structural epoxy were used to fill the cleaned out cores and a cast epoxy wafer end with all the detail of the original wood graining was laminated onto the log end (right photo). This treatment preserved the original feature with a combination of repair and replacement using substitute materials as part of a well thought out system. Photos: Courtesy of Harrison Goodall.*

substitute materials should be similarly varied so that they are not conspicuous by their uniformity.

Substitute materials, notably the masonry ones, may be more water-absorbent than the historic material. If this is visually distracting, it may be appropriate to apply a protective vapor-permeable coating on the substitute material. However, these clear coatings tend to alter the reflectivity of the material, must be reapplied periodically, and may trap salts and moisture, which can in turn produce spalling. For these reasons, they are *not* recommended for use on historic materials.

### Matching the Physical Properties

While substitute materials can closely match the appearance of historic ones, their physical properties may differ greatly. The chemical composition of the material (i.e., presence of acids, alkalines, salts, or metals) should be evaluated to ensure that the replacement materials will be compatible with the historic resource. Special care must therefore be taken to integrate and to anchor the new materials properly (see illus. 17). The thermal expansion and contraction coefficients of each adjacent material must be within tolerable limits. The function of joints must be understood and detailed either to eliminate moisture penetration or to allow vapor permeability. Materials that will cause galvanic corrosion or other chemical reactions must be isolated from one another.

To ensure proper attachment, surface preparation is critical. Deteriorated underlying material must be cleaned out. Non-corrosive anchoring devices or fasteners that are designed to carry the new material and to withstand wind, snow and other destructive elements should be used (see illus. 18). Properly chosen fasteners allow attached materials to expand and contract at their own rates. Caulking, flexible sealants or expansion joints between the historic material and the substitute material can absorb slight differences of movement. Since physical failures often result from poor anchorage or improper installation techniques, a structural engineer should be a member of any team undertaking major repairs.

Some of the new high tech materials such as epoxies and polymers are much stronger than historic materials and generally impermeable to moisture. These differences can cause serious problems unless the new materials are modified to match the expansion and contraction properties of adjacent historic materials more closely, or unless the new materials

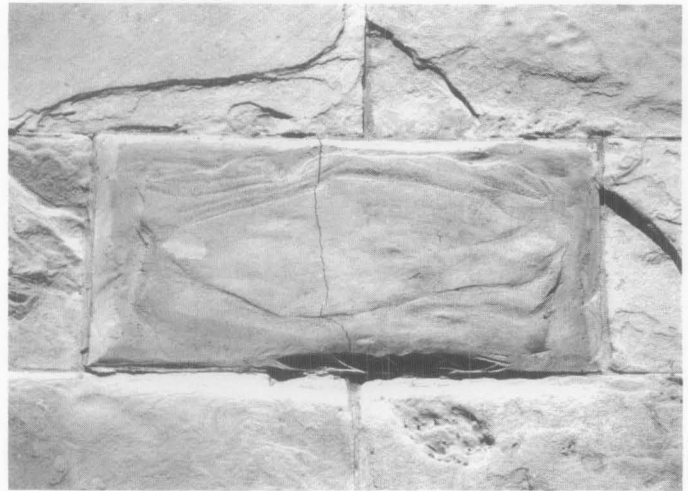
are isolated from the historic ones altogether. When stronger or vapor impermeable new materials are used alongside historic ones, stresses from trapped moisture or differing expansion and contraction rates generally hasten deterioration of the weaker historic material. For this reason, a conservative approach to repair or replacement is recommended, one that uses more pliant materials rather than high-strength ones (see illus. 19). Since it is almost impossible for substitute materials to match the properties of historic materials perfectly, the new system incorporating new and historic materials should be designed so that if material failures occur, they occur within the new material rather than the historic material.

### Performance Expectations

While a substitute material may appear to be acceptable at the time of installation, both its appearance and its performance may deteriorate rapidly. Some materials are so new that industry standards are not available, thus making it difficult to specify quality control in fabrication, or to predict maintenance requirements and long term performance. Where possible, projects involving substitute materials in similar circumstances should be examined. Material specifications outlining stability of color and texture; compressive or tensile strengths if appropriate; the acceptable range of thermal coefficients, and the durability of coatings and finishes should be included in the contract documents. Without these written documents, the owner may be left with little recourse if failure occurs (see illus. 20, 21).

The tight controls necessary to ensure long-term performance extend beyond having written performance standards and selecting materials that have a successful track record. It is important to select qualified fabricators and installers who know what they are doing and who can follow up if repairs are necessary. Installers and contractors unfamiliar with specific substitute materials and how they function in your local environmental conditions should be avoided.

The surfaces of substitute materials may need special care once installed. For example, chemical residues or mold release agents should be removed completely prior to installation, since they attract pollutants and cause the replacement materials to appear dirtier than the adjacent historic materials. Furthermore, substitute materials may require more frequent cleaning, special cleaning products and protection from impact by hanging window-cleaning scaffolding. Finally, it is critical that the substitute materials be identified as part of the historical record of the building so that proper care and maintenance of all the building materials continue to ensure the life of the historic resource.



*Illus. 19. When the physical properties are not matched, particularly thermal expansion and contraction properties, great damage can occur. In this case, an extremely rigid epoxy replacement unit was installed in a historic masonry wall. Because the epoxy was not modified with fillers, it did not expand or contract systematically with the natural stones in the wall surrounding it. Pressure built up resulting in a vertical crack at the center of the unit, and spalled edges to every historic stone that was adjacent to the rigid unit. Photo: Walter M. Sontheimer.*



*Illus. 20. Long-term performance can be affected by where the substitute material is located. In this case, fiberglass was used as part of a storefront at street level. Due to the brittle nature of the material and the frequency of impact likely to occur at this location, an unsightly chip has resulted. Photo: Sharon C. Park, AIA.*



*Illus. 21. Change of color over time is one of the greatest problems of synthetic substitute materials used outdoors. Ultra-violet light can cause materials to change color over time; some will lighten and others will darken. In this photograph, the synthetic patching material to the sandstone banding to the left of the window has aged to a darker color. Photos: Sharon C. Park, AIA.*

### **Choosing an Appropriate Substitute Material**

Once all reasonable options for repair or replacement in kind have been exhausted, the choice among a wide variety of substitute materials currently on the market must be made (see illus. 22). The charts at the end of this Brief describe a number of such materials, many of them in the family of modified concretes which are gaining greater use. The charts do not include wood, stamped metal, mineral fiber cement shingles and some other traditional imitative materials, since their properties and performance are better known. Nor do the charts include vinyls or molded urethanes which are sometimes used as cosmetic claddings or as substitutes for wooden millwork. Because millwork is still readily available, it should be replaced in kind.

The charts describe the properties and uses of several materials finding greater use in historic preservation projects, and outline advantages and disadvantages of each. It should not be read as an endorsement of any of these materials, but serves as a reminder that numerous materials must be studied carefully before selecting the appropriate treatment. Included are three predominantly masonry materials (cast stone, precast concrete, and glass fiber reinforced concrete); two predominantly resinous materials (epoxy and glass fiber reinforced polymers also known as fiberglass), and cast aluminum which has been used as a substitute for various metals and woods.



*Illus. 22. A fiber reinforced polymer (fiberglass) cornice and precast concrete elements replaced deteriorated features on the 19th-century exterior. Photo: Sharon C. Park, AIA.*

### **Summary**

Substitute materials—those products used to imitate historic materials—should be used only after all other options for repair and replacement in kind have been ruled out. Because there are so many unknowns regarding the long-term performance of substitute materials, their use should not be considered without a thorough investigation into the proposed materials, the fabricator, the installer, the availability of specifications, and the use of that material in a similar situation in a similar environment.

Substitute materials are normally used when the historic materials or craftsmanship are no longer available, if the original materials are of a poor quality or are causing damage to adjacent materials, or if there are specific code requirements that preclude the use of historic materials. Use of these materials should be limited, since replacement of historic materials on a large scale may jeopardize the integrity of a historic resource. Every means of repairing deteriorating historic materials or replacing them with identical materials should be examined *before* turning to substitute materials.

The importance of matching the appearance and physical properties of historic materials and, thus, of finding a successful long-term solution cannot be overstated. The successful solutions illustrated in this Brief were from historic preservation projects involving professional teams of architects, engineers, fabricators, and other specialists. Cost was not necessarily a factor, and all agreed that whenever possible, the historic materials should be used. When substitute materials were selected, the solutions were often expensive and were reached only after careful consideration of all options, and with the assistance of expert professionals.

## PROs and CONs of VARIOUS SUBSTITUTE MATERIALS

### Cast Aluminum

**Material:** Cast aluminum is a molten aluminum alloy cast in permanent (metal) molds or one-time sand molds which must be adjusted for shrinkage during the curing process. Color is from paint applied to primed aluminum or from a factory finished coating. Small sections can be bolted together to achieve intricate or sculptural details. Unit castings are also available for items such as column plinth blocks.

**Application:** Cast aluminum can be a substitute for cast-iron or other decorative elements. This would include grillwork, roof crestings, cornices, ornamental spandrels, storefront elements, columns, capitals, and column bases and plinth blocks. If not self-supporting, elements are generally screwed or bolted to a structural frame. As a result of galvanic corrosion problems with dissimilar metals, joint details are very important.

#### Advantages:

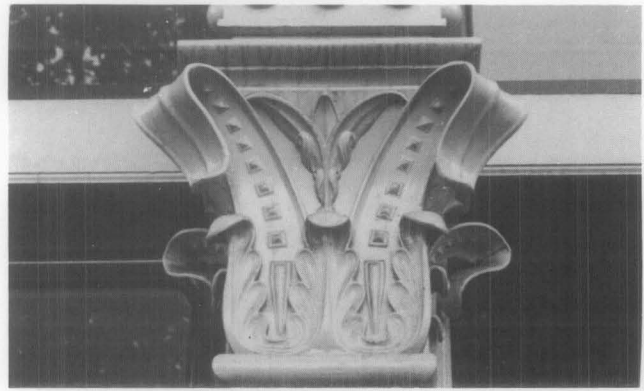
- light weight (1/2 of cast-iron)
- corrosion-resistant, non-combustible
- intricate castings possible
- easily assembled, good delivery time
- can be prepared for a variety of colors
- long life, durable, less brittle than cast iron

#### Disadvantages:

- lower structural strength than cast-iron
- difficult to prevent galvanic corrosion with other metals
- greater expansion and contraction than cast-iron; requires gaskets or caulked joints
- difficult to keep paint on aluminum

#### Checklist:

- Can existing be repaired or replaced in-kind?
- How is cast aluminum to be attached?
- Have full-size details been developed for each piece to be cast?
- How are expansion joints detailed?
- Will there be a galvanic corrosion problem?
- Have factory finishes been protected during installation?
- Are fabricators/installers experienced?



Close-up detail showing the crisp casting in aluminum of this 19th-century replica column and capital for a storefront. Photo: Sharon C. Park, AIA.



The new cast aluminum storefront replaced the lost 19th-century cast-iron original. Photo: Sharon C. Park, AIA.

## Cast Stone (*dry-tamped*):

**Material:** Cast stone is an almost-dry cement, lime and aggregate mixture which is dry-tamped into a mold to produce a dense stone-like unit. Confusion arises in the building industry as many refer to high quality precast concrete as cast stone. In fact, while it is a form of precast concrete, the dry-tamp fabrication method produces an outer surface resembling a stone surface. The inner core can be either dry-tamped or poured full of concrete. Reinforcing bars and anchorage devices can be installed during fabrication.

**Application:** Cast stone is often the most visually similar material as a replacement for unveined deteriorated stone, such as brownstone or sandstone, or terra cotta in imitation of stone. It is used both for surface wall stones and for ornamental features such as window and door surrounds, voussoirs, brackets and hoods. Rubber-like molds can be taken of good stones on site or made up at the factory from shop drawings.

### Advantages:

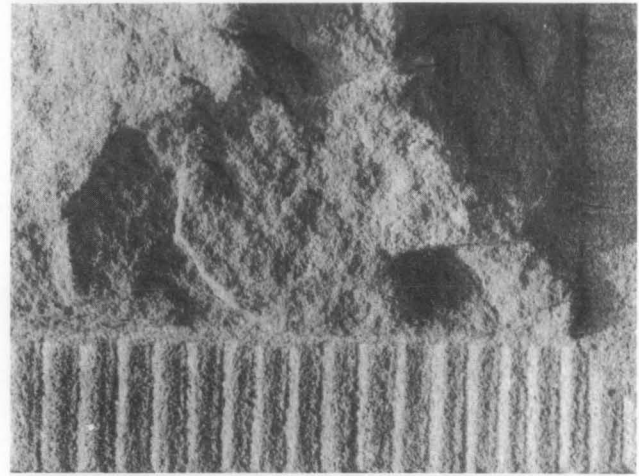
- replicates stone texture with good molds (which can come from extant stone) and fabrication
- expansion/contraction similar to stone
- minimal shrinkage of material
- anchors and reinforcing bars can be built in
- material is fire-rated
- range of color available
- vapor permeable

### Disadvantages:

- heavy units may require additional anchorage
- color can fade in sunlight
- may be more absorbent than natural stone
- replacement stones are obvious if too few models and molds are made

### Checklist:

- Are the original or similar materials available?
- How are units to be installed and anchored?
- Have performance standards been developed to ensure color stability?
- Have large samples been delivered to site for color, finish and absorption testing?
- Has mortar been matched to adjacent historic mortar to achieve a good color/tooling match?
- Are fabricators/installers experienced?



*Dry-tamped cast stone can reproduce the sandy texture of some natural stones. Photo: Sharon C. Park, AIA.*

## Glass Fiber Reinforced Concretes (GFRC)

**Material:** Glass fiber reinforced concretes are lightweight concrete compounds modified with additives and reinforced with glass fibers. They are generally fabricated as thin shelled panels and applied to a separate structural frame or anchorage system. The GFRC is most commonly sprayed into forms although it can be poured. The glass must be alkaline resistant to avoid deteriorating effects caused by the cement mix. The color is derived from the natural aggregates and if necessary a small percentage of added pigments.

**Application:** Glass fiber reinforced concretes are used in place of features originally made of stone, terra cotta, metal or wood, such as cornices, projecting window and door trims, brackets, finials, or wall murals. As a molded product it can be produced in long sections of repetitive designs or as sculptural elements. Because of its low shrinkage, it can be produced from molds taken directly from the building. It is installed with a separate non-corrosive anchorage system. As a predominantly cementitious material, it is vapor permeable.

### Advantages:

- lightweight, easily installed
- good molding ability, crisp detail possible
- weather resistant
- can be left uncoated or else painted
- little shrinkage during fabrication
- molds made directly from historic features
- cements generally breathable
- material is fire-rated

### Disadvantages:

- non-loadbearing use only
- generally requires separate anchorage system
- large panels must be reinforced
- color additives may fade with sunlight
- joints must be properly detailed
- may have different absorption rate than adjacent historic material

### Checklist:

- Are the original materials and craftsmanship still available?
- Have samples been inspected on the site to ensure detail/texture match?
- Has anchorage system been properly designed?
- Have performance standards been developed?
- Are fabricators/installers experienced?



*This glass fiber reinforced concrete sculptural wall panel will replace the seriously damaged resin and plaster original. A finely textured surface was achieved by spraying the GFRC mix into molds that were created from the historic panel and resculpted based on historic photographs. Photo: Courtesy of MJM Studios.*

## Precast Concrete

**Material:** Precast concrete is a wet mix of cement and aggregate poured into molds to create masonry units. Molds can be made from existing good surfaces on the building. Color is generally integral to the mix as a natural coloration of the sand or aggregate, or as a small percentage of pigment. To avoid unsightly air bubbles that result from the natural curing process, great care must be taken in the initial and long-term vibration of the mix. Because of its weight it is generally used to reproduce individual units of masonry and not thin shell panels.

**Application:** Precast concrete is generally used in place of masonry materials such as stone or terra cotta. It is used both for flat wall surfaces and for textured or ornamental elements. This includes wall stones, window and door surrounds, stair treads, paving pieces, parapets, urns, balusters and other decorative elements. It differs from cast stone in that the surface is more dependent on the textured mold than the hand tamping method of fabrication.

### Advantages:

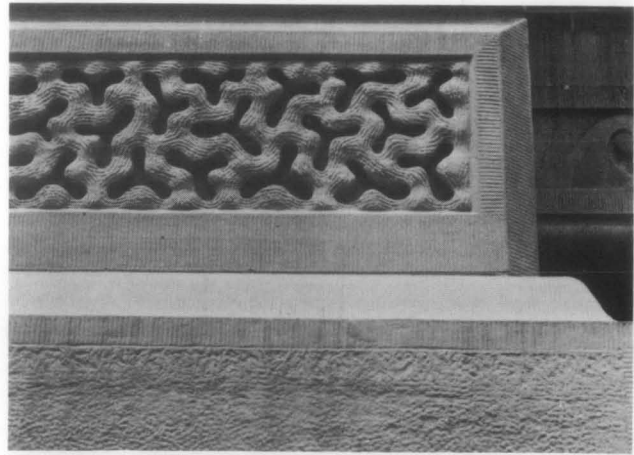
- easily fabricated, takes shape well
- rubber molds can be made from building stones
- minimal shrinkage of material
- can be load bearing or anchorage can be cast in
- expansion/contraction similar to stone
- material is fire-rated
- range of color and aggregate available
- vapor permeable

### Disadvantages:

- may be more moisture absorbent than stone although coatings may be applied
- color fades in sunlight
- heavy units may require additional anchorage
- small air bubbles may disfigure units
- replacement stones are conspicuous if too few models and molds are made

### Checklist:

- Is the historic material still available?
- What are the structural/anchorage requirements?
- Have samples been matched for color/texture/absorption?
- Have shop drawings been made for each shape?
- Are there performance standards?
- Has mortar been matched to adjacent historic mortar to achieve good color/tooling match?
- Are fabricators/installers experienced?



*Textured molds can produce a variety of high quality carved, quarried, and tooled surfaces in concrete.*

*Photo: Sharon C. Park, AIA.*

## Fiber Reinforced Polymers—

### *Known as Fiberglass*

**Material:** Fiberglass is the most well known of the FRP products generally produced as a thin rigid laminate shell formed by pouring a polyester or epoxy resin gel-coat into a mold. When tack-free, layers of chopped glass or glass fabric are added along with additional resins. Reinforcing rods and struts can be added if necessary; the gel coat can be pigmented or painted.

**Application:** Fiberglass, a non load-bearing material attached to a separate structural frame, is frequently used as a replacement where a lightweight element is needed or an inaccessible location makes frequent maintenance of historic materials difficult. Its good molding ability and versatility to represent stone, wood, metal and terra cotta make it an alternative to ornate or carved building elements such as column capitals, bases, spandrel panels, beltcourses, balustrades, window hoods or parapets. Its ability to reproduce bright colors is a great advantage.

### Advantages:

- lightweight, long spans available with a separate structural frame
- high ratio of strength to weight
- good molding ability
- integral color with exposed high quality pigmented gel-coat or takes paint well
- easily installed, can be cut, patched, sanded
- non-corrosive, rot-resistant

### Disadvantages:

- requires separate anchorage system
- combustible (fire retardants can be added); fragile to impact.
- high co-efficient of expansion and contraction requires frequently placed expansion joints
- ultra-violet sensitive unless surface is coated or pigments are in gel-coat
- vapor impermeability may require ventilation detail

### Checklist:

- Can original materials be saved/used?
- Have expansion joints been designed to avoid unsightly appearance?
- Are there standards for color stability/durability?
- Have shop drawings been made for each piece?
- Have samples been matched for color and texture?
- Are fabricators/installers experienced?
- Do codes restrict use of FRP?



*A fiberglass cornice for the reconstruction of an 18th-century wooden clockcase is being lifted in pre-fabricated sections. The level of detail is intricate and of high quality. Photo: Courtesy of Independence National Historical Park.*



## Epoxies (*Epoxy Concretes, Polymer Concretes*):

**Material:** Epoxy is a resinous two-part thermo-setting material used as a consolidant, an adhesive, a patching compound, and as a molding resin. It can repair damaged material or recreate lost features. The resins which are poured into molds are usually mixed with fillers such as sand, or glass spheres, to lighten the mix and modify their expansion/contraction properties. When mixed with aggregates, such as sand or stone chips, they are often called epoxy concrete or polymer concrete, which is a misnomer as there are no cementitious materials contained within the mix. Epoxies are vapor impermeable, which makes detailing of the new elements extremely important so as to avoid trapping moisture behind the replacement material. It can be used with wood, stone, terra cotta, and various metals.

**Application:** Epoxy is one of the most versatile of the new materials. It can be used to bind together broken fragments of terra cotta; to build up or infill missing sections of ornamental metal; or to cast missing elements of wooden ornaments. Small cast elements can be attached to existing materials or entire new features can be cast. The resins are poured into molds and due to the rapid setting of the material and the need to avoid cracking, the molded units are generally small or hollow inside. Multiple molds can be combined for larger elements. With special rods, the epoxies can be structurally reinforced. Examples of epoxy replacement pieces include: finials, sculptural details, small column capitals, and medallions.

### Advantages:

- can be used for repair/replacement
- lightweight, easily installed
- good casting ability; molds can be taken from building
- material can be sanded and carved.
- color and ultra-violet screening can be added; takes paint well
- durable, rot and fungus resistant

### Disadvantages:

- materials are flammable and generate heat as they cure and may be toxic when burned
- toxic materials require special protection for operator and adequate ventilation while curing
- material may be subject to ultra-violet deterioration unless coated or filters added
- rigidity of material often must be modified with fillers to match expansion coefficients
- vapor impermeable

### Checklist:

- Are historic materials available for molds, or for splicing-in as a repair option?
- Has the epoxy resin been formulated within the expansion/contraction coefficients of adjacent materials?
- Have samples been matched for color/finish?
- Are fabricators/installers experienced?
- Is there a sound sub-strate of material to avoid deterioration behind new material?
- Are there performance standards?



*This replica column capital was made using epoxy resins poured into a mold taken from the building. The historic wooden column shaft was repaired during the restoration. Photo: Courtesy Dell Corporation.*



*Columns were repaired and a capital was replaced in epoxy on this 19th-century 2-story porch. Photo: Dell Corporation*

## Further Reading: Substitute Materials

Berryman, Nancy D.; Susan M. Tindal, *Terra Cotta; Preservation of an Historic Material*. Chicago: Landmarks Preservation Council of Illinois, 1984.

Brookes, A.J., *Cladding of Buildings*. New York: Longman Inc., 1983.

Fisher, Thomas, "The Sincerest Form of Flattery," *Progressive Architecture* (Nov. 1985).

Gayle Margot; David W. Look, AIA; John G. Waite, *Metals in America's Historic Buildings: Uses and Preservation Treatments*. Washington, D.C.: Preservation Assistance Division, National Park Service, U.S. Department of the Interior, 1980.

*Historic Building Facades*. New York: New York Landmarks Conservancy, 1986.

Hornbostel, Caleb, *Construction Materials: Types, Uses and Applications*, New York: John Wiley and Sons, Inc., 1978.

Lynch, Michael F; William J. Higgins, *The Maintenance and Repair of Architectural Sandstone*, New York Landmarks Conservancy, 1982.

National Park Service, Rocky Mountain Regional Office, *Preservation Briefs 12: The Preservation of Historic Pigmented Structural Glass*. Washington, D.C.: Preservation Assistance Division, National Park Service, U.S. Department of the Interior, 1984.

Phillips, Morgan and Judith Selwyn, *Epoxies for Wood Repairs in Historic Buildings*. Washington, D.C.: Preservation Assistance Division, National Park Service, U.S. Department of the Interior, 1978.

Phillips, Morgan W., *The Morse-Libby Mansion: A Report on Restoration Work*. Washington, D.C.: Preservation Assistance Division, National Park Service, U.S. Department of the Interior, 1977.

Tiller, deTeel Patterson, *Preservation Briefs 7: The Preservation of Historic Glazed Architectural Terra-Cotta*. Washington, D.C.: Preservation Assistance Division, National Park Service, U.S. Department of the Interior, 1979.

## Acknowledgements

The author gratefully acknowledges the invaluable assistance of co-worker Michael Auer in editing this manuscript. The following individuals are to be thanked for their technical assistance: Mary Oehrlein A.I.A., Washington, D.C.; John G. Waite, Albany, NY; Hyman Myers, R.A., Philadelphia, PA; Thomas Fisher, Stamford, CT; Harrison Goodall, Kinnelon, NJ. In addition, the staff of Preservation Assistance Division, the cultural resources staff of the National Park Service Regional Offices, and Stan Graves, on behalf of the National Conference of State Historic Preservation Officers, provided useful comments that were incorporated into the manuscript.

This publication has been prepared pursuant to Section 101(h) of the National Historic Preservation Act, as amended, which directs the Secretary of the Interior to develop and make available information concerning historic properties. The guidance provided in this Brief will also assist property owners in complying with the requirements of the Internal Revenue Code of 1986.

Preservation Briefs: 16 has been developed under the technical editorship of Lee H. Nelson, FAIA, Chief, Preservation Assistance Division, National Park Service, U.S. Department of the Interior, P.O. Box 37127, Washington, D.C. 20013-7127. Comments on the usefulness of this information are welcome and can be sent to Mr. Nelson at the above address.

Cover photograph: Independence Hall, Philadelphia, PA; the 1972 installation of a combination wood and fiberglass clockcase duplicating the lost 18th century original. Photo: Courtesy of Independence National Historical Park.

---

For sale by the Superintendent of Documents, U.S. Government Printing Office  
Washington, D.C. 20402

# 18 PRESERVATION BRIEFS



## Rehabilitating Interiors in Historic Buildings

### Identifying and Preserving Character-defining Elements

H. Ward Jandl



U.S. Department of the Interior  
National Park Service  
Cultural Resources  
Heritage Preservation Services

A floor plan, the arrangement of spaces, and features and applied finishes may be individually or collectively important in defining the historic character of the building and the purpose for which it was constructed. Thus, their identification, retention, protection, and repair should be given prime consideration in every preservation project. Caution should be exercised in developing plans that would radically change character-defining spaces or that would obscure, damage or destroy interior features or finishes.

While the exterior of a building may be its most prominent visible aspect, or its "public face," its interior can be even more important in conveying the building's history and development over time. Rehabilitation within the context of the Secretary of the Interior's Standards for Rehabilitation calls for the preservation of exterior *and* interior portions or features of the building that are significant to its historic, architectural and cultural values.

Interior components worthy of preservation may include the building's **plan** (sequence of spaces and circulation patterns), the building's **spaces** (rooms and volumes), individual architectural **features**, and the various **finishes** and **materials** that make up the walls, floors, and ceilings. A theater auditorium or sequences of rooms such as double parlors or a lobby leading to a stairway that ascends to a mezzanine may comprise a building's most important spaces. Individual rooms may contain notable features such as plaster cornices, millwork, parquet wood floors, and hardware. Paints, wall coverings, and finishing techniques such as graining, may provide color, texture, and patterns which add to a building's unique character.

Virtually all rehabilitations of historic buildings involve some degree of interior alteration, even if the buildings are to be used for their original purpose. Interior rehabilitation proposals may range from preservation of existing features and spaces to total reconfigurations. In some cases, depending on the building, restoration may be warranted to preserve historic character adequately; in other cases, extensive alterations may be perfectly acceptable.

This Preservation Brief has been developed to assist building owners and architects in identifying and evaluating those elements of a building's interior that

contribute to its historic character and in planning for the preservation of those elements in the process of *rehabilitation*. The guidance applies to all building types and styles, from 18th century churches to 20th century office buildings. The Brief does not attempt to provide specific advice on preservation techniques and treatments, given the vast range of buildings, but rather suggests general preservation approaches to guide construction work.

### Identifying and Evaluating the Importance of Interior Elements Prior to Rehabilitation

Before determining what uses might be appropriate and before drawing up plans, a thorough professional assessment should be undertaken to identify those tangible architectural components that, prior to rehabilitation, convey the building's sense of time and place—that is, its "historic character." Such an assessment, accomplished by walking through and taking account of each element that makes up the interior, can help ensure that a truly compatible use for the building, one that requires minimal alteration to the building, is selected.

### Researching The Building's History

A review of the building's history will reveal why and when the building achieved significance or how it contributes to the significance of the district. This information helps to evaluate whether a particular rehabilitation treatment will be appropriate to the building and whether it will preserve those tangible components of the building that convey its significance for association with specific events or persons along with its architectural importance. In this regard, National Register files may prove useful in explaining why and for what period of time the

building is significant. In some cases research may show that later alterations are significant to the building; in other cases, the alterations may be without historical or architectural merit, and may be removed in the rehabilitation.

### Identifying Interior Elements

Interiors of buildings can be seen as a series of primary and secondary spaces. The goal of the assessment is to identify which elements contribute to the building's character and which do not. Sometimes it will be the sequence and flow of spaces, and not just the individual rooms themselves, that contribute to the building's character. This is particularly evident in buildings that have strong central axes or those that are consciously asymmetrical in design. In other cases, it may be the size or shape of the space that is distinctive. The importance of some interiors may not be readily apparent based on a visual inspection; sometimes rooms that do not appear to be architecturally distinguished are associated with important persons and events that occurred within the building.

**Primary spaces**, are found in all buildings, both monumental and modest. Examples may include foyers, corridors, elevator lobbies, assembly rooms, stairhalls, and parlors. Often they are the places in the building that the public uses and sees; sometimes they are the most architecturally detailed spaces in the building, carefully proportioned and finished with costly materials. They may be functionally and architecturally related to the building's external appearance. In a simpler building, a primary space may be distinguishable only by its location, size, proportions, or use. Primary spaces are always important to the character of the building and should be preserved.

**Secondary spaces** are generally more utilitarian in appearance and size than primary spaces. They may include areas and rooms that service the building, such as bathrooms, and kitchens. Examples of secondary spaces in a commercial or office structure may include storerooms, service corridors, and in some cases, the offices themselves. Secondary spaces tend to be of less importance to the building and may accept greater change in the course of work without compromising the building's historic character.

Spaces are often designed to interrelate both visually and functionally. The **sequence of spaces**, such as vestibule-hall-parlor or foyer-lobby-stair-auditorium or stairhall-corridor-classroom, can define and express the building's historic function and unique character. Important sequences of spaces should be identified and retained in the rehabilitation project.

Floor plans may also be distinctive and characteristic of a style of architecture or a region. Examples include Greek Revival and shotgun houses. Floor plans may also reflect social, educational, and medical theories of the period. Many 19th century psychiatric institutions, for example, had plans based on the ideas of Thomas Kirkbride, a Philadelphia doctor who authored a book on asylum design.

In addition to evaluating the relative importance of the various spaces, the assessment should identify architectural **features** and **finishes** that are part of the



Figure 1. This architect-designed interior reflects early 20th century American taste: the checkerboard tile floor, wood wainscot, coffered ceiling, and open staircase are richly detailed and crafted by hand. Not only are the individual architectural features worthy of preservation, but the planned sequence of spaces—entry hall, stairs, stair landings, and loggia—imparts a grandeur that is characteristic of high style residences of this period. This interior is of Greystone, Los Angeles, California. Photography for HABS by Jack E. Boucher



Figure 2. The interiors of mills and industrial buildings frequently are open, unadorned spaces with exposed structural elements. While the new uses to which this space could be put are many—retail, residential, or office—the generous floor-to-ceiling height and exposed truss system are important character-defining features and should be retained in the process of rehabilitation.

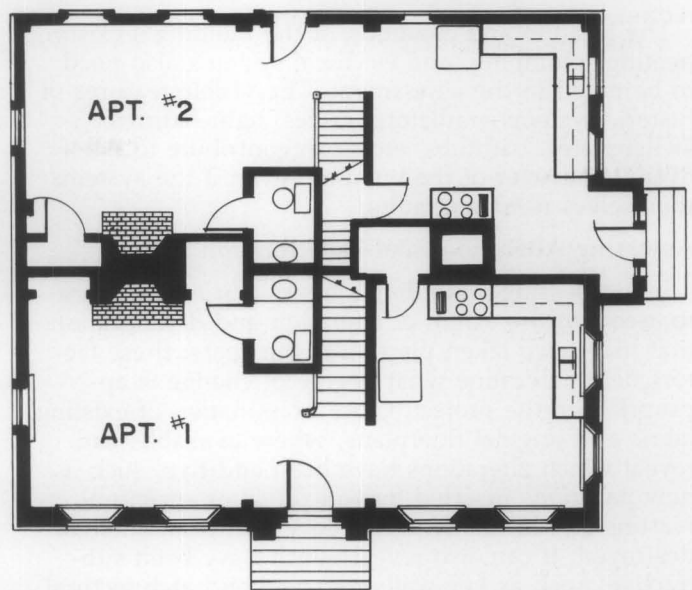
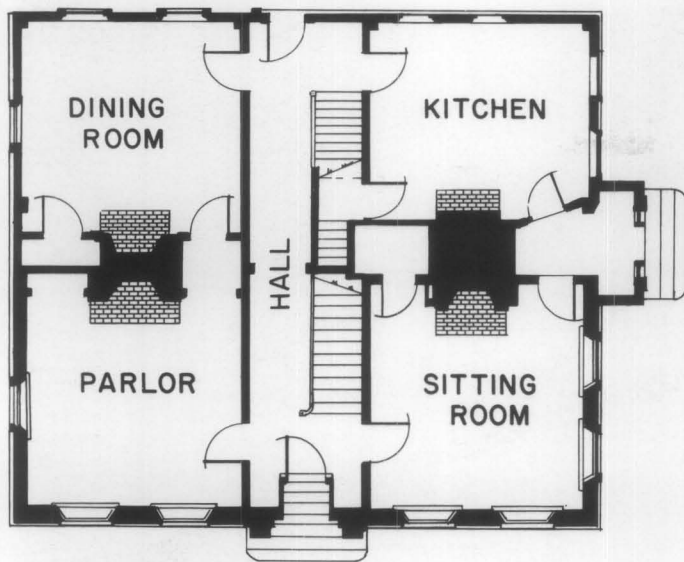


Figure 3. The floor plan at left is characteristic of many 19th century Greek Revival houses, with large rooms flanking a central hall. In the process of rehabilitation, the plan (at right) was drastically altered to accommodate two duplex apartments. The open stair was replaced with one that is enclosed, two fireplaces were eliminated, and Greek Revival trim around windows and doors was removed. The symmetry of the rooms themselves was destroyed with the insertion of bathrooms and kitchens. Few vestiges of the 19th century interior survived the rehabilitation. Drawing by Neal A. Vogel

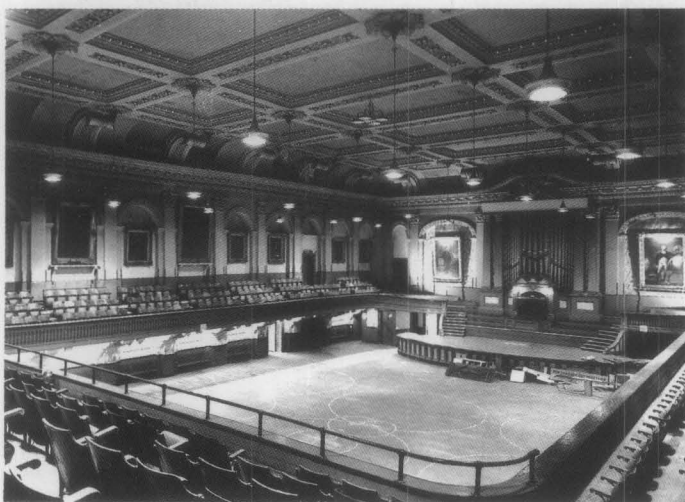


Figure 4. Many institutional buildings possess distinctive spaces or floor plans that are important in conveying the significance of the property. Finding new compatible uses for these buildings and preserving the buildings' historic character can be a difficult, if not impossible, task. One such case is Mechanics Hall in Worcester, Massachusetts, constructed between 1855 and 1857. This grand hall, which occupies the entire third floor of the building, could not be subdivided without destroying the integrity of the space.

interior's history and character. Marble or wood wainscoting in corridors, elevator cabs, crown molding, baseboards, mantels, ceiling medallions, window and door trim, tile and parquet floors, and staircases are among those features that can be found in historic buildings. Architectural finishes of note may include grained woodwork, marbled columns, and plastered walls. Those features that are characteristic of the building's style and period of construction should, again, be retained in the rehabilitation.



Figure 5. The interior of a simply detailed worker's house of the 19th century may be as important historically as the richly ornamented interior seen in figure 1. Although the interior of this house has not been properly maintained, the wide baseboards, flat window trim, and four-panel door are characteristic of workers' housing during this period and deserve retention during rehabilitation.

Features and finishes, even if machine-made and not exhibiting particularly fine craftsmanship, may be character-defining; these would include pressed metal ceilings and millwork around windows and doors. The interior of a plain, simple detailed worker's house of the 19th century may be as important historically as a richly ornamented, high-style townhouse of the same period. Both resources, if equally intact, convey important information about the early inhabitants and deserve the same careful attention to detail in the preservation process.

The location and condition of the building's existing heating, plumbing, and electrical systems also need to be noted in the assessment. The visible features of historic systems—radiators, grilles, light fixtures, switchplates, bathtubs, etc.—can contribute to the overall character of the building, even if the systems themselves need upgrading.

### Assessing Alterations and Deterioration

In assessing a building's interior, it is important to ascertain the extent of alteration and deterioration that may have taken place over the years; these factors help determine what degree of change is appropriate in the project. Close examination of existing fabric and original floorplans, where available, can reveal which alterations have been **additive**, such as new partitions inserted for functional or structural reasons and historic features covered up rather than destroyed. It can also reveal which have been **subtractive**, such as key walls removed and architectural features destroyed. If an interior has been modified by additive changes and if these changes have not acquired significance, it may be relatively easy to remove the alterations and return the interior to its historic appearance. If an interior has been greatly altered through subtractive changes, there may be more latitude in making further alterations in the process of rehabilitation because the integrity of the interior has been compromised. At the same time, if the interior had been exceptionally significant, and solid documentation on its historic condition is available, reconstruction of the missing features may be the preferred option.

It is always a recommended practice to photograph interior spaces and features thoroughly prior to rehabilitation. Measured floor plans showing the existing conditions are extremely useful. This documentation is invaluable in drawing up rehabilitation plans and specifications and in assessing the impact of changes to the property for historic preservation certification purposes.

### Drawing Up Plans and Executing Work

If the historic building is to be rehabilitated, it is critical that the new use not require substantial alteration of distinctive spaces or removal of character-defining architectural features or finishes. If an interior loses the physical vestiges of its past as well as its historic function, the sense of time and place associated both with the building and the district in which it is located is lost.

The recommended approaches that follow address common problems associated with the rehabilitation of historic interiors and have been adapted from the Secretary of the Interior's Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings. Adherence to these suggestions can help ensure that character-defining interior elements are preserved in the process of rehabilitation. The checklist covers a range of situations and is not intended to be all-inclusive. Readers are strongly encouraged to review the full set of guidelines before undertaking any rehabilitation project.



Figure 6. This corridor, located in the historic Monadnock Building in Chicago, has glazed walls, oak trim, and marble wainscoting, and is typical of those found in late 19th and early 20th century office buildings. Despite the simplicity of the features, a careful attention to detail can be noted in the patterned tile floor, bronze mail chute, and door hardware. The retention of corridors like this one should be a priority in rehabilitation projects involving commercial buildings.

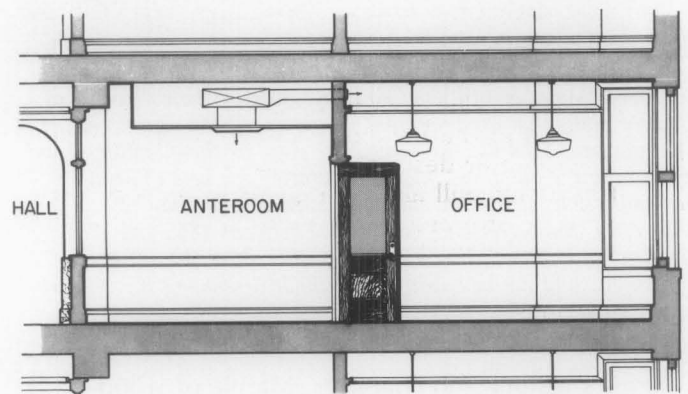


Figure 7. When the Monadnock Building was rehabilitated, architects retained the basic floor plan on the upper floors consisting of a double-loaded corridor with offices opening onto it. The original floor-to-ceiling height in the corridors and outside offices—the most important spaces—was maintained by installing needed air conditioning ductwork in the less important anterooms. In this way, the most significant interior spaces were preserved intact. Drawing by Neal A. Vogel

## Recommended Approaches for Rehabilitating Historic Interiors

1. Retain and preserve floor plans and interior spaces that are important in defining the overall historic character of the building. This includes the size, configuration, proportion, and relationship of rooms and corridors; the relationship of features to spaces; and the spaces themselves such as lobbies, reception halls, entrance halls, double parlors, theaters, auditoriums, and important industrial or commercial use spaces. Put service functions required by the building's new use, such as bathrooms, mechanical equipment, and office machines, in secondary spaces.
2. Avoid subdividing spaces that are characteristic of a building type or style or that are directly associated with specific persons or patterns of events. Space may be subdivided both vertically through the insertion of new partitions or horizontally through insertion of new floors or mezzanines. The insertion of new additional floors should be considered only when they will not damage or destroy the structural system or obscure, damage, or destroy character-defining spaces, features, or finishes. If rooms have already been subdivided through an earlier insensitive renovation, consider removing the partitions and restoring the room to its original proportions and size.
3. Avoid making new cuts in floors and ceilings where such cuts would change character-defining spaces and the historic configuration of such spaces. Inserting of a new atrium or a lightwell is appropriate only in very limited situations where the existing interiors are not historically or architecturally distinguished.
4. Avoid installing dropped ceilings below ornamental ceilings or in rooms where high ceilings are part of the building's character. In addition to obscuring or destroying significant details, such treatments will also change the space's proportions. If dropped ceilings are installed in buildings that lack character-defining spaces, such as mills and factories, they should be well set back from the windows so they are not visible from the exterior.
5. Retain and preserve interior features and finishes that are important in defining the overall historic character of the building. This might include columns, doors, cornices, baseboards, fireplaces and mantels, paneling, light fixtures, elevator cabs, hardware, and flooring; and wallpaper, plaster, paint, and finishes such as stenciling, marbleizing, and graining; and other decorative materials that accent interior features and provide color, texture, and patterning to walls, floors, and ceilings.
6. Retain stairs in their historic configuration and location. If a second means of egress is required, consider constructing new stairs in secondary spaces. (For guidance on designing compatible new additions, see Preservation Brief 14, "New Exterior Additions to Historic Buildings.") The application of fire-retardant coatings, such as intumescent paints; the installation of fire suppression systems, such as sprinklers; and the construction of glass enclosures can in many cases permit retention of stairs and other character-defining features.
7. Retain and preserve visible features of early mechanical systems that are important in defining the overall historic character of the building, such as radiators, vents, fans, grilles, plumbing fixtures, switchplates, and lights. If new heating, air conditioning, lighting and plumbing systems are installed, they should be done in a way that does not destroy character-defining spaces, features and finishes. Ducts, pipes, and wiring should be installed as inconspicuously as possible: in secondary spaces, in the attic or basement if possible, or in closets.
8. Avoid "furring out" perimeter walls for insulation purposes. This requires unnecessary removal of window trim and can change a room's proportions. Consider alternative means of improving thermal performance, such as installing insulation in attics and basements and adding storm windows.
9. Avoid removing paint and plaster from traditionally finished surfaces, to expose masonry and wood. Conversely, avoid painting previously unpainted millwork. Repairing deteriorated plasterwork is encouraged. If the plaster is too deteriorated to save, and the walls and ceilings are not highly ornamented, gypsum board may be an acceptable replacement material. The use of paint colors appropriate to the period of the building's construction is encouraged.
10. Avoid using destructive methods—propane and butane torches or sandblasting—to remove paint or other coatings from historic features. Avoid harsh cleaning agents that can change the appearance of wood. (For more information regarding appropriate cleaning methods, consult Preservation Brief 6, "Dangers of Abrasive Cleaning to Historic Buildings.")

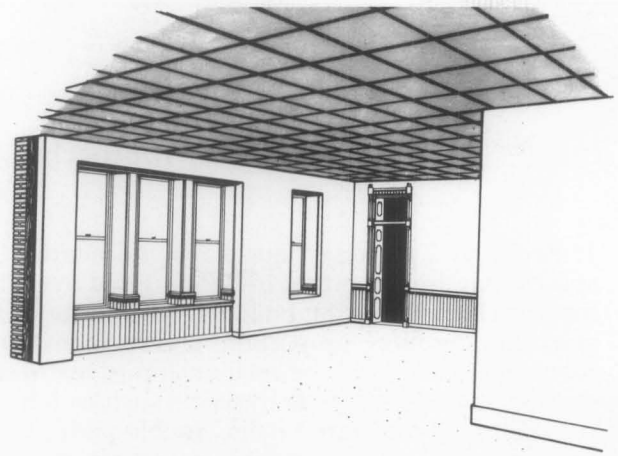
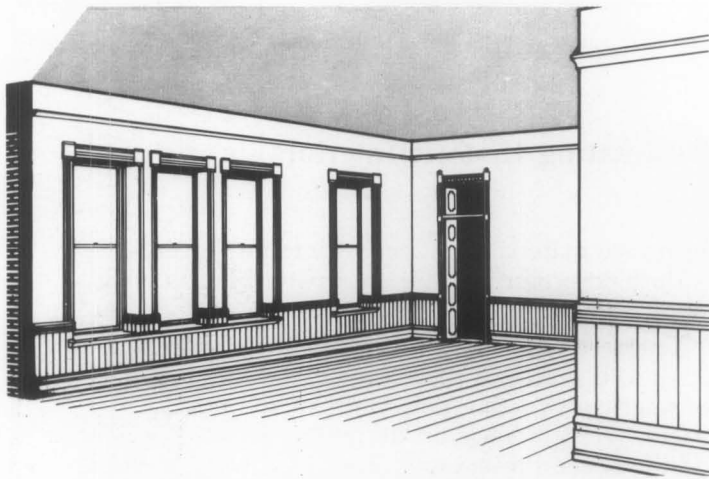


Figure 8. Furring out exterior walls to add insulation and suspending new ceilings to hide ductwork and wiring can change a room's proportions and can cause interior features to appear fragmented. In this case, a school was converted into apartments, and individual classrooms became living rooms, bedrooms, and kitchens. On the left is an illustration of a classroom prior to rehabilitation; note the generous floor-to-ceiling height, wood wainscoting, molded baseboard, picture molding, and Eastlake Style door and window trim. After rehabilitation, on the right, only fragments of the historic detailing survive: the ceiling has been dropped below the picture molding, the remaining wainscoting appears to be randomly placed, and some of the window trim has been obscured. Together with the subdivision of the classrooms, these rehabilitation treatments prevent a clear understanding of the original classroom's design and space. If thermal performance must be improved, alternatives to furring out walls and suspending new ceilings, such as installing insulation in attics and basements, should be considered. Drawings by Neal A. Vogel



Figure 9. The tangible reminders of early mechanical systems can be worth saving. In this example, in the Old Post Office in Washington, D.C., radiators encircle Corinthian columns in a decorative manner. Note, too, the period light fixtures. These features were retained when the building was rehabilitated as retail and office space. Photo: Historic American Buildings Survey



Figure 10. In this case plaster has been removed from perimeter walls, leaving brick exposed. In removing finishes from historic masonry walls, not only is there a loss of historic finish, but raw, unfinished walls are exposed, giving the interior an appearance it never had. Here, the exposed brick is of poor quality and the mortar joints are wide and badly struck. Plaster should have been retained and repaired, as necessary.





Figure 11. These dramatic "before" and "after" photographs show a severely deteriorated space restored to its original elegance: plaster has been repaired and painted, the scagliola columns have been restored to match marble using traditional craft techniques, and missing decorative metalwork has been re-installed in front of the windows. Although some reorganization of the space took place, notably the relocation of the front desk, the overall historic character of the space has been preserved. These views are of the lobby in the Willard Hotel, Washington, D.C. Credit: Commercial Photographers (left); Carol M. Highsmith (right)

## Meeting Building, Life Safety and Fire Codes

Buildings undergoing rehabilitation must comply with existing building, life safety and fire codes. The application of codes to specific projects varies from building to building, and town to town. Code requirements may make some reuse proposals impractical; in other cases, only minor changes may be needed to bring the project into compliance. In some situations, it may be possible to obtain a code variance to preserve distinctive interior features. (It should be noted that the Secretary's Standards for Rehabilitation take precedence over other regulations and codes in determining whether a rehabilitation project qualifies for Federal tax benefits.) A thorough understanding of the applicable regulations and close coordination with code officials, building inspectors, and fire marshals can prevent the alteration of significant historic interiors.

### Sources of Assistance

Rehabilitation and restoration work should be undertaken by professionals who have an established reputation in the field.

Given the wide range of interior work items, from ornamental plaster repair to marble cleaning and the application of graining, it is possible that a number of specialists and subcontractors will need to be brought in to bring the project to completion. State Historic Preservation Officers and local preservation organizations may be a useful source of information in this regard. Good sources of information on appropriate preservation techniques for specific interior features and finishes include the *Bulletin of the Association for Preservation Technology* and *The Old-House Journal*; other useful publications are listed in the bibliography.

## Protecting Interior Elements During Rehabilitation

Architectural features and finishes to be preserved in the process of rehabilitation should be clearly marked on plans *and at the site*. This step, along with careful supervision of the interior demolition work and protection against arson and vandalism, can prevent the unintended destruction of architectural elements that contribute to the building's historic character.

Protective coverings should be installed around architectural features and finishes to avoid damage in the course of construction work and to protect workers. Staircases and floors, in particular, are subjected to dirt and heavy wear, and the risk exists of incurring costly or irreparable damage. In most cases, the best, and least costly, preservation approach is to design and construct a protective system that enables stairs and floors to be used yet protects them from damage. Other architectural features such as mantels, doors, wainscoting, and decorative finishes may be protected by using heavy canvas or plastic sheets.

### Summary

In many cases, the interior of a historic building is as important as its exterior. The careful identification and evaluation of interior architectural elements, after undertaking research on the building's history and use, is critically important *before* changes to the building are contemplated. Only *after* this evaluation should new uses be decided and plans be drawn up. The best rehabilitation is one that preserves and protects those rooms, sequences of spaces, features and finishes that define and shape the overall historic character of the building.

This Preservation Brief is based on a discussion paper prepared by the author for a National Park Service regional workshop held in March, 1987, and on a paper written by Gary Hume, "Interior Spaces in Historic Buildings," October, 1987. Appreciation is extended to the staff of Technical Preservation Services Branch and to the staff of NPS regional offices who reviewed the manuscript and provided many useful suggestions. Special thanks are given to Neal A. Vogel, a summer intern with the NPS, for many of the illustrations in this Brief.

This publication has been prepared pursuant to the National Historic Preservation Act of 1966, as amended. Preservation Briefs 18 was developed under the editorship of Lee H. Nelson, FAIA, Chief, Preservation Assistance Division, National Park Service, U.S. Department of the Interior, P.O. Box 37127, Washington, D.C. 20013-7127. Comments on the usefulness of this information are welcomed and may be sent to Mr. Nelson at the above address. This publication is not copyrighted and can be reproduced without penalty. Normal procedures for credit to the author and the National Park Service are appreciated.

### Selected Reading List

There are few books written exclusively on preserving historic interiors, and most of these tend to focus on residential interiors. Articles on the subject appear regularly in *The Old-House Journal*, the *Bulletin of the Association for Preservation Technology*, and *Historic Preservation Magazine*.

Ferro, Maximilian L., and Melissa L. Cook. *Electric Wiring and Lighting in Historic American Buildings*. New Bedford, Massachusetts: AFC/A Nortek Company, 1984.

Fisher, Charles E. *Temporary Protection of Historic Stairways During Rehabilitation Work*. Preservation Tech Note. Washington, D.C.: Preservation Assistance Division, National Park Service, U.S. Department of the Interior, 1985.

Jennings, Jan, and Herbert Gottfried. *American Vernacular Interior Architecture 1870-1940*. New York: Van Nostrand Reinhold Company, 1988.

Johnson, Ed. *Old House Woodwork Restoration: How to Restore Doors, Windows, Walls, Stairs and Decorative Trim to Their Original Beauty*. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1983.

Labine, Clem, and Carolyn Flaherty (editors). *The Old-House Journal Compendium*. Woodstock, New York: The Overlook Press, 1980.

*The Secretary of the Interior's Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings*. Washington, D.C.: Preservation Assistance Division, National Park Service, U.S. Department of the Interior, rev. 1983.

U.S. Department of Housing and Urban Development. *Rehabilitation Guidelines*, volumes 1-11. Washington, D.C.: U.S. Department of Housing and Urban Development, 1980-84.

Winkler, Gail Caskey, and Roger W. Moss. *Victorian Interior Decoration: American Interiors 1830-1900*. New York: Henry Holt and Company, 1986.

October 1988

Cover: Detail of carving on interior shutter. Hammond-Harwood House, Annapolis, Maryland.

# 24 PRESERVATION BRIEFS

## Heating, Ventilating, and Cooling Historic Buildings: Problems and Recommended Approaches

Sharon C. Park, AIA

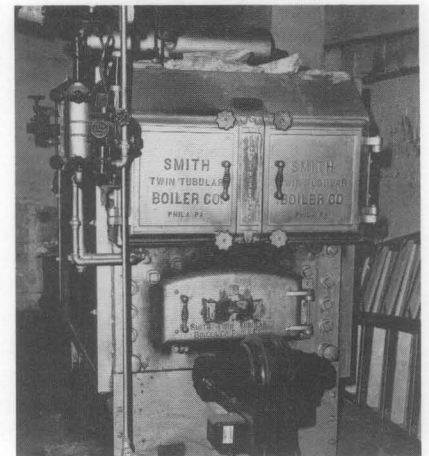


U.S. Department of the Interior  
National Park Service  
Cultural Resources  
Heritage Preservation Services

The need for modern mechanical systems is one of the most common reasons to undertake work on historic buildings. Such work includes upgrading older mechanical systems, improving the energy efficiency of existing buildings, installing new heating, ventilation or air conditioning (HVAC) systems, or—particularly for museums—installing a climate control system with humidification and dehumidification capabilities. Decisions to install new HVAC or climate control systems often result from concern for occupant health and comfort, the desire to make older buildings marketable, or the need to provide specialized environments for operating computers, storing artifacts, or displaying museum collections. Unfortunately, occupant comfort and concerns for the objects within the building are sometimes given greater consideration than the building itself. In too many cases, applying modern standards of interior climate comfort to historic buildings has proven detrimental to historic materials and decorative finishes.

This Preservation Brief underscores the importance of careful planning in order to balance the preservation objectives with interior climate needs of the building. It is not intended as a technical guide to calculate tonnage or to size piping or ductwork. Rather, this Brief identifies some of the problems associated with installing mechanical systems in historic buildings and recommends approaches to minimizing the physical and visual damage associated with installing and maintaining these new or upgraded systems.

Historic buildings are not easily adapted to house modern precision mechanical systems. Careful planning must be provided early on to ensure that decisions made during the design and installation phases of a new system are appropriate. Since new mechanical and other related systems, such as electrical and fire suppression, can use up to 10% of a building's square footage and 30%–40% of an overall rehabilitation budget, decisions must be made in a systematic and coordinated manner. The installation of inappropriate



mechanical systems may result in any or all of the following:

- large sections of historic materials are removed to install or house new systems.
- historic structural systems are weakened by carrying the weight of, and sustaining vibrations from, large equipment.
- moisture introduced into the building as part of a new system migrates into historic materials and causes damage, including biodegradation, freeze/thaw action, and surface staining.
- exterior cladding or interior finishes are stripped to install new vapor barriers and insulation.
- historic finishes, features, and spaces are altered by dropped ceilings and boxed chases or by poorly located grilles, registers, and equipment.
- systems that are too large or too small are installed before there is a clearly planned use or a new tenant.

For historic properties it is critical to understand what spaces, features, and finishes are historic in the building, what should be retained, and what the *realistic* heating, ventilating, and cooling needs are for the building, its occupants, and its contents. A systematic approach, involving preservation planning, preservation design, and a follow-up program of monitoring and maintenance, can ensure that new systems are successfully added—or existing systems are suitably upgraded—while preserving the historic integrity of the building.

No set formula exists for determining what type of mechanical system is best for a specific building. Each building and its needs must be evaluated separately. Some buildings will be so significant that every effort must be made to protect the historic materials and systems in place with minimal intrusion from new systems. Some buildings will have museum collections that need special climate control. In such cases, curatorial needs must be considered—but not to the ultimate detriment of the historic building resource. Other

buildings will be rehabilitated for commercial use. For them, a variety of systems might be acceptable, as long as significant spaces, features, and finishes are retained.

Most mechanical systems require upgrading or replacement within 15–30 years due to wear and tear or the availability of improved technology. Therefore, historic buildings should not be greatly altered or otherwise sacrificed in an effort to meet short-term systems objectives.

### History of Mechanical Systems

The history of mechanical systems in buildings involves a study of inventions and ingenuity as building owners, architects, and engineers devised ways to improve the interior climate of their buildings. Following are highlights in the evolution of heating, ventilating, and cooling systems in historic buildings.

**Eighteenth Century.** Early heating and ventilation in America relied upon common sense methods of *managing the environment* (see figure 1). Builders purposely sited houses to capture winter sun and prevailing summer cross breezes; they chose materials that could help protect the inhabitants from the elements, and took precautions against precipitation and damaging drainage patterns. The location and sizes of windows, doors, porches, and the floor plan itself often evolved to maximize ventilation. Heating was primarily from fireplaces or stoves and, therefore, was at the source of delivery. In 1744, Benjamin Franklin designed his "Pennsylvania stove" with a fresh air intake in order to maximize the heat radiated into the room and to minimize annoying smoke.

Thermal insulation was rudimentary—often wattle and daub, brick and wood nogging. The comfort level for occupants was low, but the relatively small difference between internal and external temperatures and relative humidity allowed building materials to expand and contract with the seasons.

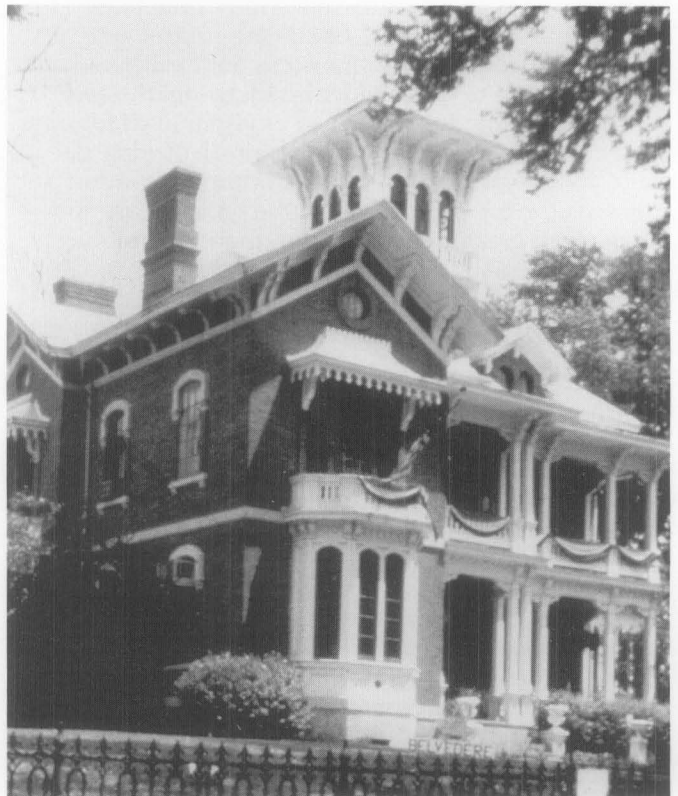
Regional styles and architectural features reflected regional climates. In warm, dry and sunny climates, thick adobe walls offered shelter from the sun and kept the inside temperatures cool. Verandas, courtyards, porches, and high ceilings also reduced the impact of the sun. Hot and humid climates called for elevated living floors, louvered grilles and shutters, balconies, and interior courtyards to help circulate air.

**Nineteenth Century.** The industrial revolution provided the technological means for *controlling the environment* for the first time (see figure 2). The dual developments of steam energy from coal and industrial mass production made possible early central heating systems with distribution of heated air or steam using metal ducts or pipes. Improvements were made to early wrought iron boilers and by late century, steam and low pressure hot water radiator systems were in common use, both in offices and residences. Some large institutional buildings heated air in furnaces and distributed it throughout the building in brick flues with a network of metal pipes delivering heated air to individual rooms. Residential designs of the period often used gravity hot air systems utilizing decorative floor and ceiling grilles.

Ventilation became more scientific and the introduc-



1. Eighteenth century and later vernacular architecture depended on the siting of the building, deciduous trees, cross ventilation, and the placement of windows and chimneys to maximize winter heating and natural summer cooling. Regional details, as seen in this Virginia house, include external chimneys and a separate summer kitchen to reduce fire risk and isolate heat in the summer. Photo: NPS Files.



2. Nineteenth century buildings continued to use architectural features such as porches, cupolas, and awnings to make the buildings more comfortable in summer, but heating was greatly improved by hot water or steam radiators. Photo: NPS Files

tion of fresh air into buildings became an important component of heating and cooling. Improved forced air ventilation became possible in mid-century with the introduction of power-driven fans. Architectural features such as porches, awnings, window and door transoms, large open-work iron roof trusses, roof monitors, cupolas, skylights and clerestory windows helped to dissipate heat and provide healthy ventilation.

Cavity wall construction, popular in masonry structures, improved the insulating qualities of a building and also provided a natural cavity for the dissipation of moisture produced on the interior of the building. In some buildings, cinder chips and broken masonry filler between structural iron beams and jack arch floor vaults provided thermal insulation as well as fire-proofing. Mineral wool and cork were new sources of lightweight insulation and were forerunners of contemporary batt and blanket insulation.

The technology of the age, however, was not sufficient to produce "tight" buildings. There was still only a moderate difference between internal and external temperatures. This was due, in part, to the limitations of early insulation, the almost exclusive use of single glazed windows, and the absence of air-tight construction. The presence of ventilating fans and the reliance on architectural features, such as operable windows, cupolas and transoms, allowed sufficient air movement to keep buildings well ventilated. Building materials could behave in a fairly traditional way, expanding and contracting with the seasons.

**Twentieth Century.** The twentieth century saw intensive development of new technologies and the notion of fully *integrating mechanical systems* (see figure 3). Oil and gas furnaces developed in the nineteenth century were improved and made more efficient, with electricity becoming the critical source of power for building systems in the latter half of the century. Forced air heating systems with ducts and registers became popular for all types of buildings and allowed architects to experiment with architectural forms free from mechanical encumbrances. In the 1920s large-scale theaters and auditoriums introduced central air conditioning, and by mid-century forced air systems which combined heating and air conditioning in the same ductwork set a new standard for comfort and convenience. The combination and coordination of a variety of systems came together in the post-World War II highrise buildings; complex heating and air conditioning plants, electric elevators, mechanical towers, ventilation fans, and full service electric lighting were integrated into the building's design.

The insulating qualities of building materials improved. Synthetic materials, such as spun fiberglass batt insulation, were fully developed by mid-century. Prototypes of insulated thermal glazing and integral storm window systems were promoted in construction journals. Caulking to seal out perimeter air around window and door openings became a standard construction detail.

The last quarter of the twentieth century has seen making HVAC systems more energy efficient and better integrated. The use of vapor barriers to control moisture migration, thermally efficient windows, caulking

and gaskets, compressed thin wall insulation, has become standard practice. New integrated systems now combine interior climate control with fire suppression, lighting, air filtration, temperature and humidity control, and security detection. Computers regulate the performance of these integrated systems based on the time of day, day of the week, occupancy, and outside ambient temperature.



3. The circa 1928 Fox Theater in Detroit, designed by C. Howard Crane, was one of the earliest twentieth century buildings to provide air conditioning to its patrons. The early water-cooled system was recently restored. Commercial and highrise buildings of the twentieth century were able, mostly through electrical power, to provide sophisticated systems that integrated many building services. Photo: William Kessler and Associates, Architects.

### Climate Control and Preservation

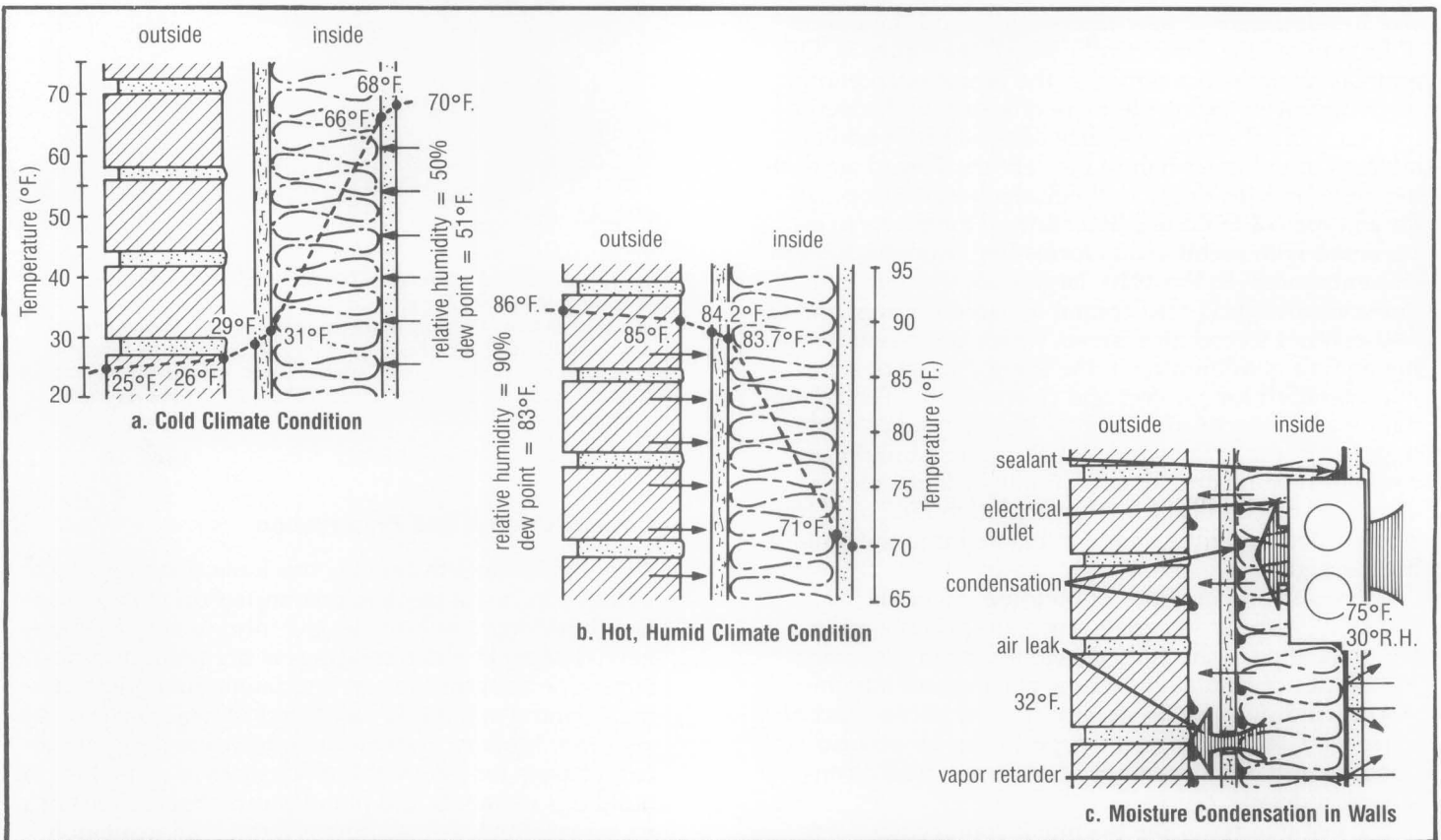
Although twentieth century mechanical systems technology has had a tremendous impact on making historic buildings comfortable, the introduction of these new systems in older buildings is not without problems. The attempt to meet and maintain modern climate control standards *may in fact be damaging to historic resources*. Modern systems are often over-designed to compensate for inherent inefficiencies of some historic buildings materials and plan layouts. Energy retrofit measures, such as installing exterior wall insulation and vapor barriers or the sealing of operable window and vents, ultimately affect the performance and can reduce the life of aging historic materials.

In general, the greater the differential between the interior and exterior temperature and humidity levels, the greater the potential for damage. As natural vapor pressure moves moisture from a warm area to a colder, dryer area, condensation will occur on or in building materials in the colder area (see figure 4). Too little humidity in winter, for example, can dry and crack historic wooden or painted surfaces. Too much humidity in winter causes moisture to collect on cold surfaces, such as windows, or to migrate into walls. As a result, this condensation deteriorates wooden or metal windows and causes rotting of walls and wooden structural elements, dampening insulation and holding moisture against exterior surfaces. Moisture migration through walls can cause the corrosion of metal anchors, angles, nails or wire lath, can blister and peel exterior paint, or can leave efflorescence and salt deposits on exterior masonry. In cold climates, freeze-thaw damage can result from excessive moisture in external walls.

To avoid these types of damage to a historic building, it is important to understand how building components work together as a system. Methods for controlling interior temperature and humidity and improving ventilation must be considered in any new or upgraded HVAC or climate control system. While certain energy retrofit measures will have a positive effect on the overall building, installing effective vapor barriers in historic walls is difficult and often results in destruction of significant historic materials (see figure 5).



5. The installation of vapor retarders in walls of historic buildings in an effort to contain interior moisture can cause serious damage to historic finishes as shown here. In this example, all the wall plaster and lath have been stripped in preparation for a vapor barrier prior to replastering. Controlling interior temperature and relative humidity can be more effective than adding insulation and vapor barriers to historic perimeter walls. Photo: Ernest A. Conrad, P.E.



4. Mechanical heating and cooling systems change the interior climate of a building. Moisture in the air will dissipate from the warmer area of a building to the colder area and can cause serious deterioration of historic materials. Condensation can form if the dew point occurs within the building wall, particularly one that has been insulated (see a and b). Even when vapor retarders are installed (c), any non-continuous areas will provide spaces for moisture to pass. Wall Section Drawings: NPS files

## Planning the New System

Climate control systems are generally classified according to the medium used to condition the temperature: air, water, or a combination of both (see overview on page 6). The complexity of choices facing a building owner or manager means that a *systematic approach* is critical in determining the most suitable system for a building, its contents, and its occupants. No matter which system is installed, a change in the interior climate will result. This physical change will in turn affect how the building materials perform. New registers, grilles, cabinets, or other accessories associated with the new mechanical system will also visually change the interior (and sometimes the exterior) appearance of the building. Regardless of the type or extent of a mechanical system, the owner of a historic building should know *before* a system is installed what it will look like and what problems can be anticipated during the life of that system. The potential harm to a building and costs to an owner of selecting the wrong mechanical system are very great.

The use of a building and its contents will largely determine the best type of mechanical system. The historic building materials and construction technology as well as the size and availability of secondary spaces within the historic structure will affect the choice of a system. It may be necessary to investigate a combination of systems. In each case, the needs of the user, the needs of the building, and the needs of a collection or equipment must be considered. It may not be necessary to have a comprehensive climate control system if climate-sensitive objects can be accommodated in special areas or climate-controlled display cases. It may not be necessary to have central air conditioning in a mild climate if natural ventilation systems can be improved through the use of operable windows, awnings, exhaust fans, and other "low-tech" means. Modern standards for climate control developed for new construction may not be achievable or desirable for historic buildings. *In each case, the lowest level of intervention needed to successfully accomplish the job should be selected.*

Before a system is chosen, the following planning steps are recommended:

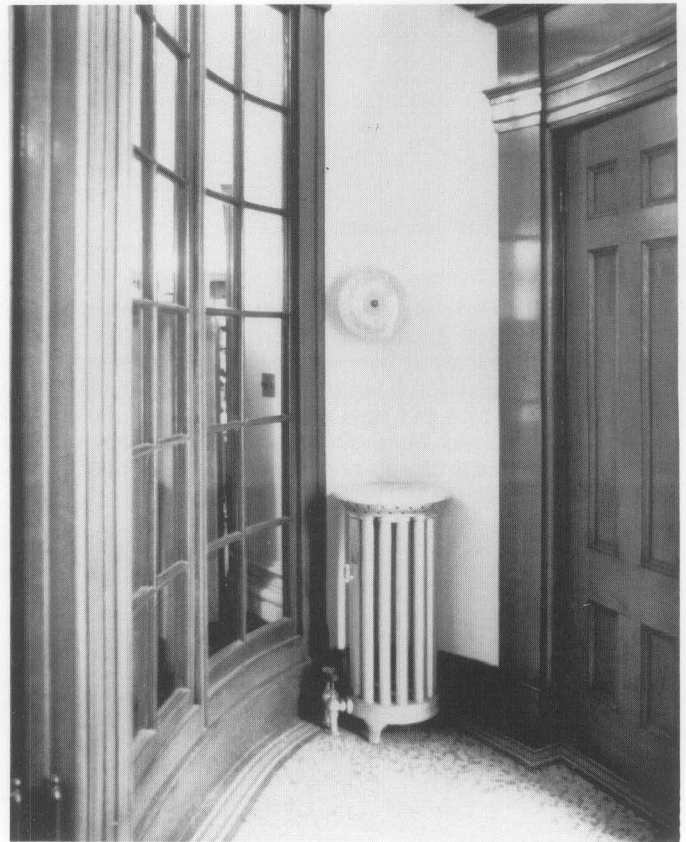
1. **Determine the use of the building.** The proposed use of the building (museum, commercial, residential, retail) will influence the type of system that should be installed. The number of people and functions to be housed in a building will establish the level of comfort and service that must be provided. Avoid uses that require major modifications to significant architectural spaces. What is the intensity of use of the building: intermittent or constant use, special events or seasonal events? Will the use of the building require major new services such as restaurants, laundries, kitchens, locker rooms, or other areas that generate moisture that may exacerbate climate control within the historic space? In the context of historic preservation, uses that require radical reconfigurations of historic spaces are inappropriate for the building.

2. **Assemble a qualified team.** This team ideally should consist of a preservation architect, mechanical engineer, electrical engineer, structural engineer, and preservation consultants, each knowledgeable in codes and local requirements. If a special use (church, mu-

seum, art studio) or a collection is involved, a specialist familiar with the mechanical requirements of that building type or collection should also be hired.

Team members should be familiar with the needs of historic buildings and be able to balance complex factors: the preservation of the historic architecture (aesthetics and conservation), requirements imposed by mechanical systems (quantified heating and cooling loads), building codes (health and safety), tenant requirements (quality of comfort, ease of operation), access (maintenance and future replacement), and the overall cost to the owner.

3. **Undertake a condition assessment of the existing building and its systems.** What are the existing construction materials and mechanical systems? What condition are they in and are they reusable (see figure 6)? Where are existing chillers, boilers, air handlers, or cooling towers located? Look at the condition of all other services that may benefit from being integrated into a new system, such as electrical and fire suppression systems. Where can energy efficiency be improved to help downsize any new equipment added, and which of the historic features, e.g. shutters, awnings, skylights, can be reused (see figure 7)? Evaluate air infiltration through the exterior envelope; monitor the interior for temperature and humidity levels with hygrometers for at least a year. Identify building, site, or equipment deficiencies or the presence of asbestos that must be corrected prior to the installation or upgrading of mechanical systems.



6. A condition assessment during the planning stage would identify this round radiator in a small oval-shaped vestibule as a significant element of the historic heating system. In upgrading the mechanical system, the radiator should be retained. Photo: Michael C. Henry, P.E., AIA.

# Overview of HVAC Systems

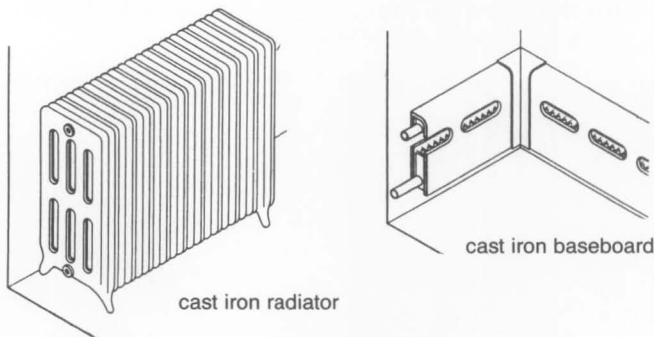
## WATER SYSTEMS: Hydronic radiators, Fan coil, or radiant pipes

Water systems are generally called *hydronic* and use a network of pipes to deliver water to hot water radiators, radiant pipes set in floors or fan coil cabinets which can give both heating and cooling. Boilers produce hot water or steam; chillers produce chilled water for use with fan coil units. Thermostats control the temperature by zone for radiators and radiant floors. Fan coil units have individual controls. Radiant floors provide quiet, even heat, but are not common.

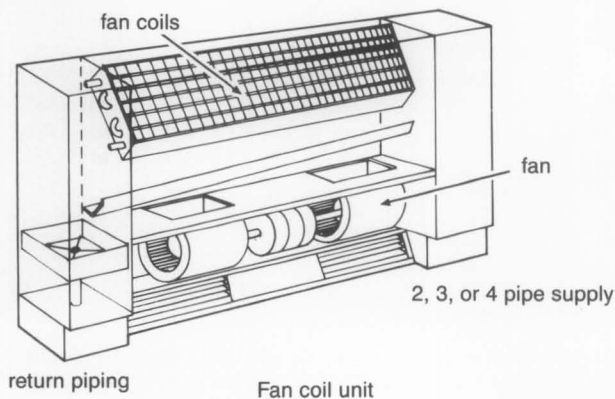
**Advantages:** Piped systems are generally easier to install in historic buildings because the pipes are smaller than ductwork.

**Disadvantages:** There is the risk, however, of hidden leaks in the wall or burst pipes in winter if boilers fail. Fan coil condensate pans can overflow if not properly maintained. Fan coils may be noisy.

**Hydronic Radiators:** Radiators or baseboard radiators are looped together and are usually set under windows or along perimeter walls. New boilers and circulating pumps can upgrade older systems. Most piping was cast iron although copper systems can be used if separately zoned. Modern cast iron baseboards and copper fin-tubes are available. Historic radiators can be reconditioned.



**Fan Coil Units:** Fan coil systems use terminal cabinets in each room serviced by 2, 3, or 4 pipes approximately 1-1/2" each in diameter. A fan blows air over the coils which are serviced by hot or chilled water. Each fan coil cabinet can be individually controlled. Four-pipe fan coils can provide both heating and cooling all year long. Most piping is steel. Non-cabinet units may be concealed in closets or custom cabinetry, such as benches, can be built.



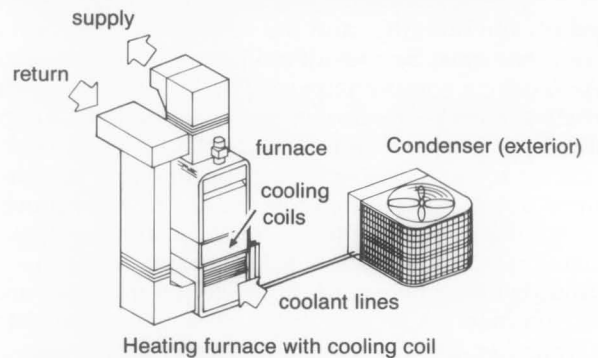
## CENTRAL AIR SYSTEMS

The basic heating, ventilation and air conditioning (HVAC) system is all-air, single zone fan driven designed for low, medium or high pressure distribution. The system is composed of compressor drives, chillers, condensers, and furnace depending on whether the air is heated, chilled or both. Condensers, generally air cooled, are located outside. The ducts are sheet metal or flexible plastic and can be insulated. Fresh air can be circulated. Registers can be designed for ceilings, floors and walls. The system is controlled by thermostats; one per zone.

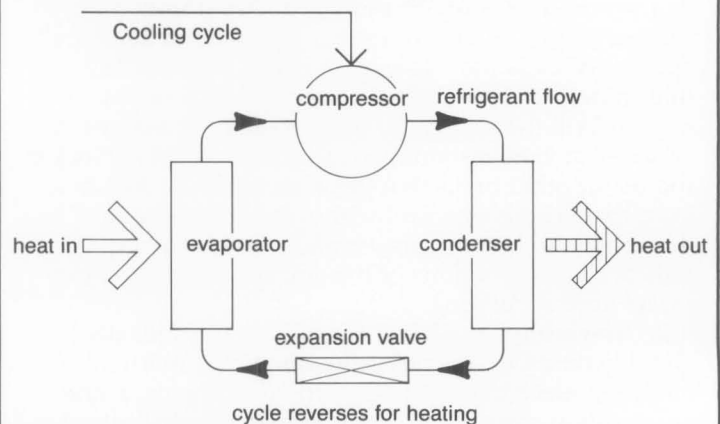
**Advantages:** Ducted systems offer a high level of control of interior temperature, humidity, and filtration. Zoned units can be relatively small and well concealed.

**Disadvantages:** The damage from installing a ducted system without adequate space can be serious for a historic building. Systems need constant balancing and can be noisy.

**Basic HVAC:** Most residential or small commercial systems will consist of a basic furnace with a cooling coil set in the unit and a refrigerant compressor or condenser located outside the building. Heating and cooling ductwork is usually shared. If sophisticated humidification and dehumidification is added to the basic HVAC system, a full climate control system results. This can often double the size of the equipment.



**Basic Heat Pump/Air System:** The heat pump is a basic HVAC system as described above except for the method of generating hot and cold air. The system operates on the basic refrigeration cycle where latent heat is extracted from the ambient air and is used to evaporate refrigerant vapor under pressure. Functions of the condenser and evaporator switch when heating is needed. Heat pumps, somewhat less efficient in cold climates, can be fitted with electric resistance coil.





## COMBINED AIR AND WATER SYSTEMS

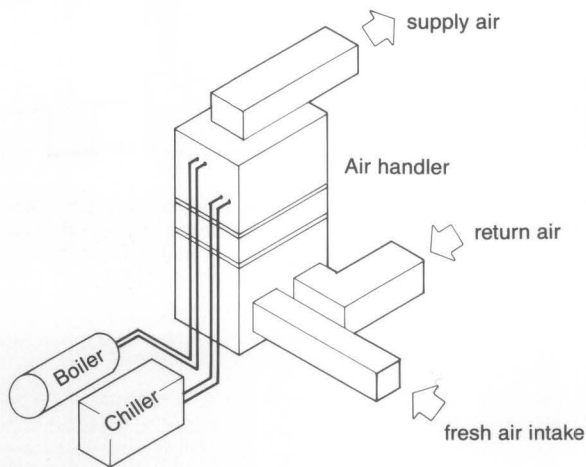
These systems are popular for restoration work because they combine the ease of installation for the piped system with the performance and control of the ducted system. Smaller air handling units, not unlike fan coils, may be located throughout a building with service from a central boiler and chiller. In many cases the water is delivered from a central plant which services a complex of buildings.

This system overcomes the disadvantages of a central ducted system where there is not adequate horizontal or vertical runs for the ductwork. The equipment, being smaller, may also be quieter and cause less vibration. If only one air handler is being utilized for the building, it is possible to house all the equipment in a vault outside the building and send only conditioned air into the structure.

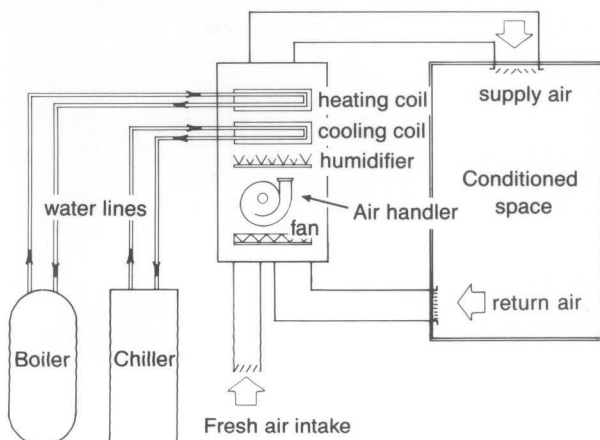
**Advantages:** flexibility for installation using greater piping runs with shorter ducted runs; Air handlers can fit into small spaces.

**Disadvantages:** piping areas may have undetected leaks; air handlers may be noisy.

### Water-serviced Air Handlers:



### Typical Systems Layout:



## OTHER SYSTEM COMPONENTS

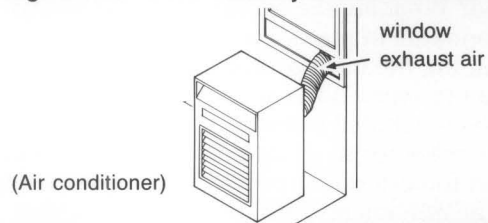
Non-systems components should not be overlooked if they can make a building more comfortable without causing damage to the historic resource or its collection.

**Advantages:** components may provide acceptable levels of comfort without the need for an entire system.

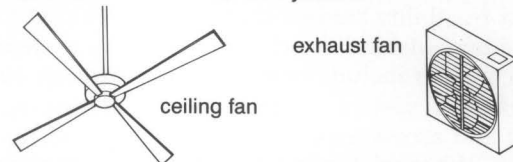
**Disadvantages:** Spot heating, cooling and fluctuations in humidity may harm sensitive collections or furnishings. If an integrated system is desirable, components may provide only a temporary solution.

### Portable Air Conditioning:

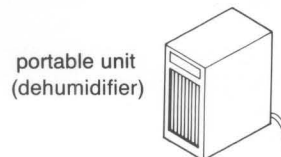
Most individual air conditioners are set in windows or through exterior walls which can be visually as well as physically damaging to historic buildings. Newer portable air conditioners are available which sit in a room and exhaust directly to the exterior through a small slot created by a raised window sash.



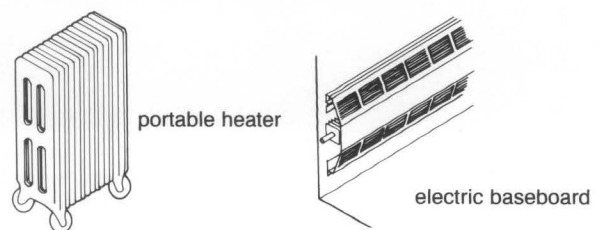
**Fans:** Fans should be considered in most properties to improve ventilation. Fans can be located in attics, at the top of stairs, or in individual rooms. In moderate climates, fans may eliminate the need to install central air systems.



**Dehumidifiers:** For houses without central air handling systems, a dehumidifier can resolve problems in humid climates. Seasonal use of dehumidifiers can remove moisture from damp basements and reduce fungal growth.



**Heaters:** Portable radiant heaters, such as those with water and glycol, may provide temporary heat in buildings used infrequently or during systems breakdowns. Care should be taken not to create a fire hazard with improperly wired units.



4. **Prioritize architecturally significant spaces, finishes, and features to be preserved.** Significant architectural spaces, finishes and features should be identified and evaluated at the outset to ensure their preservation. This includes significant existing mechanical systems or elements such as hot water radiators, decorative grilles, elaborate switchplates, and non-mechanical architectural features such as cupolas, transoms, or porches. Identify non-significant spaces where mechanical equipment can be placed and secondary spaces where equipment and distribution runs on both a horizontal and vertical basis can be located. Appropriate secondary spaces for housing equipment might include attics, basements, penthouses, mezzanines, false ceiling or floor cavities, vertical chases, stair towers, closets, or exterior below-grade vaults (see figure 8).

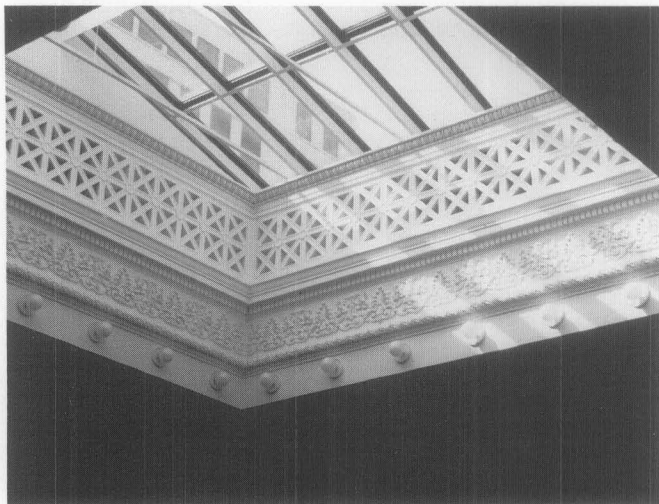
5. **Become familiar with local building and fire codes.** Owners or their representatives should meet early and often with local officials. Legal requirements should be checked; for example, can existing ductwork be reused or modified with dampers? Is asbestos abatement required? What are the energy, fire, and safety codes and standards in place, and how can they be met while maintaining the historic character of the building? How are fire separation walls and rated mechanical systems to be handled between multiple tenants? Is there a requirement for fresh air intake for stair towers that will affect the exterior appearance of the building? Many of the health, energy, and safety code requirements will influence decisions made for mechanical equipment for climate control. It is important to know what they are before the design phase begins.

6. **Evaluate options for the type and size of systems.** A matrix or feasibility studies should be developed to balance the benefits and drawbacks of various systems. Factors to consider include heating and/or cooling, fuel type, distribution system, control devices, generating equipment and accessories such as filtration, and humidification. What are the initial installation costs, projected fuel costs, long-term maintenance, and life-cycle

costs of these components and systems? Are parts of an existing system being reused and upgraded? The benefits of added ventilation should not be overlooked (see figure 9). What are the trade-offs between one large central system and multiple smaller systems? Should there be a forced air ducted system, a 2-pipe fan coil system, or a combined water and air system? What space is available for the equipment and distribution system? Assess the fire-risk levels of various fuels. Understand the advantages and disadvantages of the various types of mechanical systems available. *Then evaluate each of these systems in light of the preservation objectives established during the design phase of planning.*



8. In considering options for new systems, existing spaces should be evaluated for their ability to house new equipment. This sketch shows several areas where new mechanical equipment could be located to avoid damaging significant spaces. Sketch: NPS files



7. Operable skylights and grilles that can be adapted for return air should be identified as part of the planning phase for new or upgraded mechanical systems. Photo: Dianne Pierce, NPS files.



9. Improving ventilation through traditional means should not be overlooked in planning new or upgraded HVAC systems. In mild climates, good exhaust fans can often eliminate the need for air conditioning or can reduce equipment size by reducing cooling loads. Photo: Ernest A. Conrad, P.E.

## Designing the new system

In designing a system, it is important to anticipate how it will be installed, how damage to historic materials can be minimized, and how visible the new mechanical system will be within the restored or rehabilitated spaces (see figure 10 a-f). Mechanical equipment space needs are often overwhelming; in some cases, it may be advantageous to look for locations outside of the building, including ground vaults, to house some of the equipment but only if it there is no adverse impact to the historic landscape or adjacent archeological resources. Various means for reducing the heating and cooling loads (and thereby the size of the equipment) should be investigated. This might mean reducing slightly the comfort levels of the interior, increasing the number of climate control zones, or improving the energy efficiency of the building.

The following activities are suggested during the design phase of the new system:

**1. Establish specific criteria for the new or upgraded mechanical system.** New systems should be *installed with a minimum of damage to the resource and should be visually compatible with the architecture of the building.* They should be installed in a way that is *easy to service, maintain, and upgrade in the future.* There should be *safety and back-up monitors in place* if buildings have collections, computer rooms, storage vaults or special conditions that need monitoring. The new systems should work within the structural limits of the historic building. They should produce *no undue vibration, no undue noise, no dust or mold, and no excess moisture* that could damage the historic building materials. If any equipment is to be located outside of the building, there should be *no impact to the historic appearance of building or site, and there should be no impact on archeological resources.*

**2. Prioritize the requirements for the new climate control system.** The use of the building will determine the level of interior comfort and climate control. Sometimes, various temperature zones may safely be created within a historic building. This zoned approach may be appropriate for buildings with specialized collections storage, for buildings with mixed uses, or for large buildings with different external exposures, occupancy patterns, and delivery schedules for controlled air. Special archives, storage vaults or computer rooms may need a completely different climate control from the rest of the building. Determine temperature and humidity levels for occupants and collections and ventilation requirements between differing zones. Establish if the system is to run 24 hours a day or only during operating or business hours. Determine what controls are optimum (manual, computer, preset automatic, or other). The size and location of the equipment to handle these different situations will ultimately affect the design of the overall system as well.

**3. Minimize the impact of the new HVAC on the existing architecture.** Design criteria for the new system should be based on the type of architecture of the historic resource. Consideration should be given as to whether or not the delivery system is visible or hidden. Utilitarian and industrial spaces may be capable of

accepting a more visible and functional system. More formal, ornate spaces which may be part of an interpretive program may require a less visible or disguised system. A ducted system should be installed without ripping into or boxing out large sections of floors, walls, or ceilings. A wet pipe system should be installed so that hidden leaks will not damage important decorative finishes. In each case, not only the type of system (air, water, combination), but its distribution (duct, pipe) and delivery appearance (grilles, cabinets, or registers) must be evaluated. It may be necessary to use a combination of different systems in order to preserve the historic building. Existing chases should be reused whenever possible.

**4. Balance quantitative requirements and preservation objectives.** The ideal system may not be achievable for each historic resource due to cost, space limitations, code requirements, or other factors beyond the owner's control. However, significant historic spaces, finishes, and features can be preserved in almost every case, even given these limitations. For example, if some ceiling areas must be slightly lowered to accommodate ductwork or piping, these should be in secondary areas away from decorative ceilings or tall windows. If modern fan coil terminal units are to be visible in historic spaces, consideration should be given to custom designing the cabinets or to using smaller units in more locations to diminish their impact. If grilles and registers are to be located in significant spaces, they should be designed to work within the geometry or placement of decorative elements. All new elements, such as ducts, registers, pipe-runs, and mechanical equipment should be installed in a reversible manner to be removed in the future without further damage to the building (see fig 11).

## Systems Performance and Maintenance

Once the system is installed, it will require routine maintenance and balancing to ensure that the proper performance levels are achieved. In some cases, extremely sophisticated, computerized systems have been developed to control interior climates, but these still need monitoring by trained staff. If collection exhibits and archival storage are important to the resource, the climate control system will require constant monitoring and tuning. Back-up systems are also needed to prevent damage when the main system is not working. The owner, manager, or chief of maintenance should be aware of all aspects of the new climate control system and have a plan of action before it is installed.

Regular training sessions on operating, monitoring, and maintaining the new system should be held for both curatorial and building maintenance staff. If there are curatorial reasons to maintain constant temperature or humidity levels, only individuals thoroughly trained in how the HVAC systems operates should be able to adjust thermostats. Ill-informed and haphazard attempts to adjust comfort levels, or to save energy over weekends and holidays, can cause great damage.

10. The following photographs illustrate recent preservation projects where careful planning and design retained the historic character of the resources.

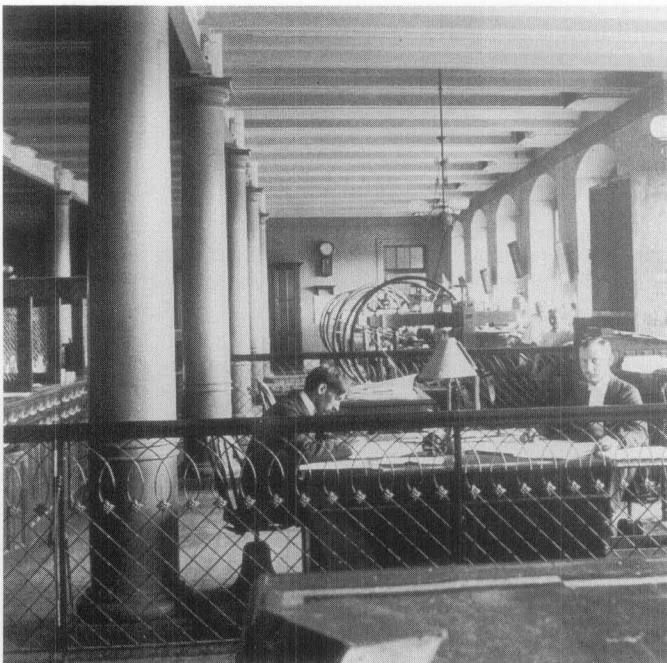


before



after

a. Before and after of a circa 1900 school entrance. The radiators have been replaced with a two-pipe fan coil system built into bench seats. The ceiling was preserved and no exposed elements were required to add air conditioning. Piping runs are under the benches and there was no damage to the masonry walls. Photos: Notter Finegold + Alexander Inc. and Lautman Photography, Washington.



historic



after

d. Auditors Buildings, Washington, D.C. This upper floor workspace had been modified over the years with dropped ceilings and partitions. In the recent restoration, the open plan workspace was restored, the false ceiling was removed, and the fireproof construction was exposed. A variable air volume (VAV) system using round double shell exposed ductwork is in keeping with the industrial character of the architectural space. Photo: Kenneth Wyner Photography, courtesy of Notter Finegold + Alexander Inc. Before view provided by Notter Finegold + Alexander/Mariani.



b. Central air conditioning was installed in the corridors of this circa 1900 school building by adding an air handler over the entrance from a vestibule. The custom-designed slot registers provide linear diffusers without detracting from the architecture of the space. Photo: Lautman Photography courtesy of Notter Finegold + Alexander Inc.



c. Conference room, Auditors Building, Washington, D.C. The historic steam radiators were retained for heating. The cast iron ceiling register was retained as a decorative element, but made inoperable to meet fire codes. Photo: Kenneth Wyner Photography courtesy of Notter Finegold + Alexander Inc.



e. Town Hall, Andover, MA. The upstairs auditorium was restored and new mechanical systems were installed. Perimeter baseboard radiation provides heat and air handlers, located in the attic space provide air conditioning. The cast iron ceiling grille was adapted for return air and the supply registers were installed in a symmetrical and regular manner to minimize impact on the historic ceiling. Photo: David Hewitt/Anne Garrison for Ann Beha Associates.



f. Homewood, Baltimore, MD. This elegant circa 1806 residence is now a house museum. The registers for the forced air ducted system seen behind the table legs, are grained to blend with the historic baseboards. The HVAC system uses a water/air system where chilled water and steam heat are converted to conditioned air. Photo: Courtesy Homewood Museum, Johns Hopkins University.

## HVAC Do's and Don'ts

### DO's:

- Use shutters, operable windows, porches, curtains, awnings, shade trees and other historically appropriate non-mechanical features of historic buildings to reduce the heating and cooling loads. Consider adding sensitively designed storm windows to existing historic windows.
- Retain or upgrade existing mechanical systems whenever possible: for example, reuse radiator systems with new boilers, upgrade ventilation within the building, install proper thermostats or humidistats.
- Improve energy efficiency of existing buildings by installing insulation in attics and basements. Add insulation and vapor barriers to exterior walls *only* when it can be done without further damage to the resource.
- In major spaces, retain decorative elements of the historic system whenever possible. This includes switchplates, grilles and radiators. Be creative in adapting these features to work within the new or upgraded system.
- Use space in existing chases, closets or shafts for new distribution systems.
- Design climate control systems that are compatible with the architecture of the building: hidden system for formal spaces, more exposed systems possible in industrial or secondary spaces. In formal areas, avoid standard commercial registers and use custom slot registers or other less intrusive grilles.
- Size the system to work within the physical constraints of the building. Use multi-zoned smaller units in conjunction with existing vertical shafts, such as stacked closets, or consider locating equipment in vaults underground, if possible.
- Provide adequate ventilation to the mechanical rooms as well as to the entire building. Selectively install air intake grilles in less visible basement, attic, or rear areas.
- Maintain appropriate temperature and humidity levels to meet requirements without accelerating the deterioration of the historic building materials. Set up regular monitoring schedules.
- Design the system for maintenance access and for future systems replacement.
- For highly significant buildings, install safety monitors and backup features, such as double pans, moisture detectors, lined chases, and battery packs to avoid or detect leaks and other damage from system failures.

- Have a regular maintenance program to extend equipment life and to ensure proper performance.
- Train staff to monitor the operation of equipment and to act knowledgeably in emergencies or breakdowns.
- Have an emergency plan for both the building and any curatorial collections in case of serious malfunctions or breakdowns.

---

### DON'TS:

- Don't install a new system if you don't need it.
- Don't switch to a new type of system (e.g. forced air) unless there is sufficient space for the new system or an appropriate place to put it.
- Don't over-design a new system. Don't add air conditioning or climate control if they are not absolutely necessary.
- Don't cut exterior historic building walls to add through-wall heating and air conditioning units. These are visually disfiguring, they destroy historic fabric, and condensation runoff from such units can further damage historic materials.
- Don't damage historic finishes, mask historic features, or alter historic spaces when installing new systems.
- Don't drop ceilings or bulkheads across window openings.
- Don't remove repairable historic windows or replace them with inappropriately designed thermal windows.
- Don't seal operable windows, unless part of a museum where air pollutants and dust are being controlled.
- Don't place condensers, solar panels, chimney stacks, vents or other equipment on visible portions of roofs or at significant locations on the site.
- Don't overload the building structure with the weight of new equipment, particularly in the attic.
- Don't place stress on historic building materials through the vibrations of the new equipment.
- Don't allow condensation on windows or within walls to rot or spall adjacent historic building materials.

Maintenance staff should learn how to operate, monitor, and maintain the mechanical equipment. They must know where the maintenance manuals are kept. Routine maintenance schedules must be developed for changing and cleaning filters, vents, and condensate pans to control fungus, mold, and other organisms that are dangerous to health. Such growths can harm both inhabitants and equipment. (In piped systems, for example, molds in condensate pans can block drainage lines and cause an overflow to leak onto finished surfaces). Maintenance staff should also be able to monitor the appropriate gauges, dials, and thermographs. Staff must be trained to intervene in emergencies, to know where the master controls are, and whom to call in an emergency. As new personnel are hired, they will also require maintenance training.

In addition to regular cyclical maintenance, thorough inspections should be undertaken from time to time to evaluate the continued performance of the climate control system. As the system ages, parts are likely to fail, and signs of trouble may appear. Inadequately ventilated areas may smell musty. Wall surfaces may show staining, wet patches, bubbling or other signs of moisture damage. Routine tests for air quality, humidity, and temperature should indicate if the system is performing properly. If there is damage as a result of the new system, it should be repaired immediately and then closely monitored to ensure complete repair.

Equipment must be accessible for maintenance and should be visible for easy inspection. Moreover, since mechanical systems last only 15–30 years, the system itself must be “reversible.” That is, the system must be installed in such a way that later removal will not damage the building. In addition to servicing, the back-up monitors that signal malfunctioning equipment must be routinely checked, adjusted, and maintained. Checklists should be developed to ensure that all aspects of routine maintenance are completed and that data is reported to the building manager.



a

## Conclusion

The successful integration of new systems in historic buildings can be challenging. Meeting modern HVAC requirements for human comfort or installing controlled climates for museum collections or for the operation of complex computer equipment can result in both visual and physical damage to historic resources. Owners of historic buildings must be aware that the final result will involve balancing multiple needs; no perfect heating, ventilating, and air conditioning system exists. In undertaking changes to historic buildings, it is best to have the advice and input of trained professionals who can:

- assess the condition of the historic building,
- evaluate the significant elements that should be preserved or reused,
- prioritize the preservation objectives,
- understand the impact of new interior climate conditions on historic materials,
- integrate preservation with mechanical and code requirements,
- maximize the advantages of various new or upgraded mechanical systems,
- understand the visual and physical impact of various installations,
- identify maintenance and monitoring requirements for new or upgraded systems, and
- plan for the future removal or replacement of the system.

Too often the presumed climate needs of the occupants or collections can be detrimental to the long-term preservation of the building. With a careful balance between the preservation needs of the building and the interior temperature and humidity needs of the occupants, a successful project can result.



b

11. During the restoration of this 1806 National Historic Landmark (photo a), a new climate control system was installed. The architects removed all the earlier mechanical equipment from the house and installed new equipment in a 30' × 40' concrete vault located underground 150 feet from the house itself (photo b). Only conditioned air is blown into the house reusing much of the circa 1930s ductwork. Photos: Thomas C. Jester.

## Bibliography

- Banham, Reyner. *The Architecture of the Well-Tempered Environment*. London: The Architectural Press, 1969.
- Burns, John A., AIA. *Energy Conserving Features Inherent in Older Homes*. Washington: U.S. Department of Housing and Urban Development and U.S. Department of the Interior, 1982.
- Cowan, Henry J. *Science and Building; Structural and Environmental Design in the Nineteenth and Twentieth Centuries*. New York: John Wiley & Sons, 1978.
- Ferguson, Eugene S. "An Historical Sketch of Central Heating: 1800-1860," in *Building Early America* (Charles Peterson, editor) Philadelphia: Chilton Book Co., 1976.
- Fitch, James Marston. *American Building; The Environmental Forces That Shape It*. Boston: Houghton Mifflin Co., 1972.
- Giedion, Siegfried. *Mechanization Takes Command; a Contribution to Anonymous History*. New York: Oxford University Press, 1948.
- Merritt, Frederick S. *Building Engineering and Systems Design*. New York: Van Nostrand Reinhold Co, 1979.
- Smith, Baird M. *Preservation Briefs 3: Conserving Energy in Historic Buildings*. Washington, DC: U.S. Department of the Interior, 1978.
- Turberg, Edward. *A History of American Building Technology*. Durham: Durham Technical Institute, 1981.

## Acknowledgements

The author gratefully acknowledges the invaluable assistance of Michael C. Henry, P.E., AIA, in the development and technical editing of this Preservation Brief. Technical review was also provided by Ernest A. Conrad, P.E. Thanks is also given to staff members of the National Park Service Cultural Resources Programs, including Tom Keohan and Catherine Colby, Rocky Mountain Region; Michael Crowe, Western Region; Mark Chavez, Midwest Region; Randall J. Biallas, AIA, Chief, Park Historic Architecture Division, and George A. Thorsen, Historical Architect, Denver Service Center. Special thanks is also given to Michael J. Auer of Technical Preservation Services for his editorial assistance in preparing this paper and Tim Buehner for his assistance with the illustrations.

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. Preservation Brief 24 was developed under the editorship of H. Ward Jandl, Chief, Technical Preservation Services. Comments on the usefulness of this publication may be directed to Chief, Technical Preservation Services Branch, Preservation Assistance Division, National Park Service, P.O. Box 37127, Washington, D.C. 20013-7127. This publication is not copyrighted and can be reproduced without penalty. Normal procedures for credit to the author and the National Park Service are appreciated.



# 41 PRESERVATION BRIEFS

## The Seismic Rehabilitation of Historic Buildings

Antonio Aguilar



National Park Service  
U.S. Department of the Interior

Technical Preservation Services



Earthquakes result from sudden movements of the geological plates that form the earth's crust, generally along cracks or fractures known as "faults." When buildings are not designed and constructed to withstand these unpredictable and often violent ground motions, major structural damage, or outright collapse, can result, with grave risk to human life. Historic buildings are especially vulnerable to seismic events, particularly those built before seismic codes were adopted. Also, more and more communities continue to adopt higher standards for seismic retrofit of existing buildings. And, despite popular misconceptions, the risks of earthquakes are not limited to the West Coast (Figures 1 and 7), but exist across much of the United States.

Although historic and other older buildings can be retrofitted to survive earthquakes, the process of doing so may damage or destroy the very features that make such buildings significant. While life-safety issues remain foremost concerns, fortunately, there are various approaches which can help protect historic buildings from both the devastation caused by earthquakes and from the damage inflicted by well-intentioned, but insensitive, retrofit procedures. Building owners, managers, consultants, and communities need to be actively involved in planning for and readying irreplaceable historic resources from these threats.

This Preservation Brief provides information on how earthquakes affect historic buildings, how a historic preservation ethic can guide responsible retrofit decisions, and how various methods of seismic rehabilitation can protect human lives and historic structures. The Brief provides a description of the most common vulnerabilities of various building construction types and the seismic strengthening methods most often needed to remedy them. A glossary of technical terms is also provided at the end of the Brief.

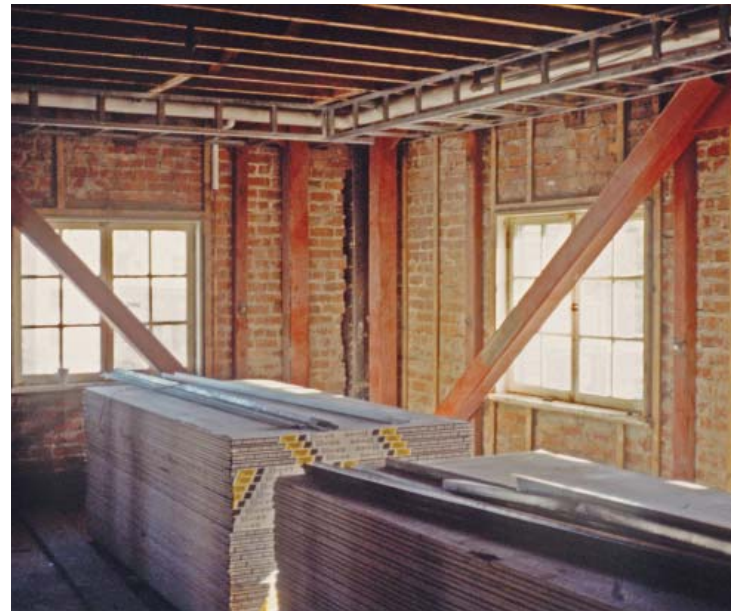
Undertaking the seismic rehabilitation of a historic building is a process that requires careful planning and execution, and the coordinated work of architects, engineers, code officials, contractors, and agency administrators. Project personnel working together can ensure that the architectural, structural, financial, programmatic, cultural, and social values of historic buildings are preserved, while rendering them safe for continued use.

### Achieving Seismic Retrofit as well as Preservation

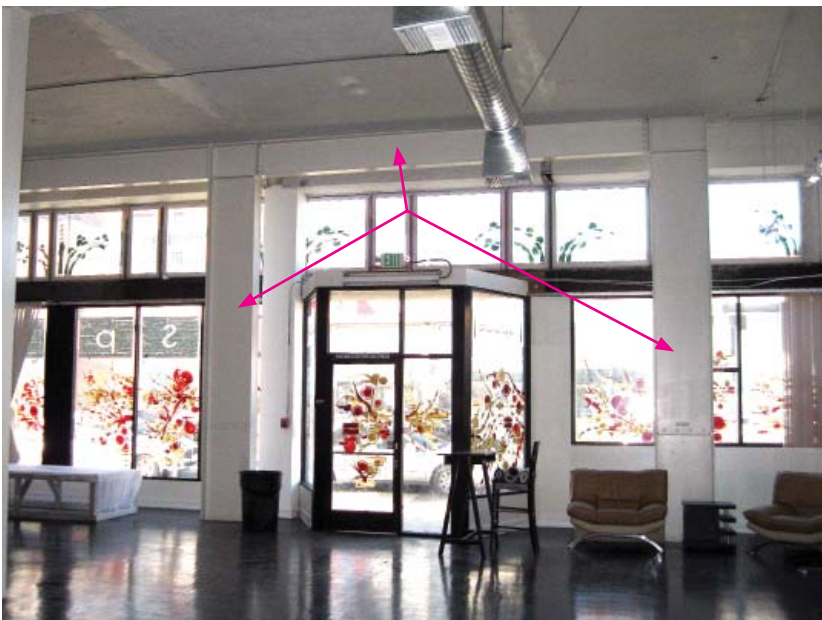
Major repairs and alterations, additions, change in occupancy, and local ordinances can trigger compliance with current building code requirements, including seismic strengthening requirements that specify a minimum level of protection from earthquake hazards to building occupants. They also specify the process for the seismic evaluation of buildings, outline the methods for rehabilitation, specify limitations



Figure 1. In 2011, a 5.6 magnitude earthquake substantially damaged all four turrets atop St. Gregory's University Benedictine Hall in Shawnee, Oklahoma. Photo: St. Gregory University.



Figures 2-3. Standard approaches to seismic rehabilitation, such as adding diagonal bracing to reinforce window and storefront openings as seen in these photos, can be visually intrusive. Figure 2 (left). Figure 3 (right). Photo: Steade Craig.



Figures 4-5. Using moment frames (horizontal and vertical steel members identified by the arrows) set back behind storefront openings as seen in Figure 4 (left), or placing brace frames (in red) away from the windows as illustrated in Figure 5 (right) are solutions that meet historic preservation goals. Figure 4. Photo: Elizabeth Hilton.

on selecting structural analysis procedures, identify acceptable rehabilitation strategies, and specify when alternative compliance methods may be used.

Building codes are primarily intended to guide the design and construction of new buildings and often require the application of certain design and construction methods that are critical for good seismic performance. However, determining the seismic adequacy of historic buildings by comparing them to the requirements for new construction can be difficult, and sometimes impossible, because some archaic building materials and construction methods are not included in the new building codes. While many jurisdictions have adopted prescriptive standards, primarily for certain building types such as unreinforced masonry load bearing walls, more sophisticated, performance-based evaluation methods allowed by some codes offer more flexibility.

Many prescriptive code complying standards can result in the destruction of much of a historic building's appearance and integrity. This is because the most expedient way to reinforce a building is to introduce a completely new complying structural system, to add new structural members, and to fill in irregularities or large openings without regard to how the new structural elements or modifications affect its architectural design. The results of these approaches can be quite intrusive (Figures 2-3). However, structural reinforcement can be introduced sensitively while still meeting code requirements. In such cases, its design, placement, patterning, and detailing will respect the historic character of the building, even when the reinforcement itself is visible (Figures 4-5).

Successful seismic rehabilitations of historic buildings require both skillful use of the best available technology

as well a proper understanding of historic preservation, and the inherent strength of archaic materials and structural systems. The seismic retrofit of historic buildings is as much an art as it is a science; it is, therefore, extremely important to select a professional who is not only experienced with seismic rehabilitation of existing buildings, but is also closely familiar with *The Secretary of the Interior's Standards for the Treatment of Historic Properties*. While some degree of change or alteration to a historic building may be inevitable and acceptable in a seismic rehabilitation, the Standards can provide critical decision-making guidance in the process of planning and designing a successful seismic rehabilitation. The goal of a successful seismic rehabilitation should be to reduce the seismic vulnerabilities of a building while retaining its historic materials and features to the greatest extent possible and avoiding or minimizing alterations to significant historic features and spaces.

**Four important preservation principles should be kept in mind when undertaking seismic retrofit projects:**

- Historic features and materials, both structural and nonstructural, should be preserved and retained, not as museum artifacts, but to continue to fulfill their historic function to the greatest extent possible, and not be replaced wholesale in the process of seismic strengthening.
- If historic features and materials are damaged beyond repair, or must be removed during the retrofit, they should be replaced in kind or with compatible substitute materials. If they must be removed during the retrofit, they should be removed carefully and thoroughly documented to ensure they can be properly re-installed in their original location.
- New seismic retrofit systems should work in concert with the inherent strengths of the historic structural system, and, whether hidden or exposed, should respect the character and integrity of the historic building, be visually unobtrusive and compatible in design, and be selected and designed with due consideration to limiting the damage to historic features and materials during installation.
- Seismic work should be reversible whenever feasible to allow its removal for future installation of improved systems as well as repair of historic features and materials.

**Earthquakes and Historic Buildings:  
Assessing Principal Risk Factors**

The Federal Emergency Management Agency (FEMA) defines seismic risk as a function of earthquake hazard and vulnerability. Assessing the seismic risk of a historic property is the first step to avoid the potential loss of life and injuries, damage and loss of property, or disruption of services. Seismic evaluations of historic buildings within areas of earthquake hazard should be conducted

**Putting a Team Together**

A team that is experienced with both seismic retrofit requirements and historic preservation, and can adopt an inter-disciplinary approach, is important for achieving a seismic rehabilitation that is sensitive to the building's historic character, features, and materials. Team members should be selected for their experience with similar projects, and may include architects, engineers, code specialists, contractors, and preservation consultants. Because the typical seismic codes are written for new construction, it is important that both the architect and structural engineer be knowledgeable about historic buildings and about meeting building code equivalencies and finding other options.

Local and state building officials can identify regulatory requirements, alternative approaches to meeting these requirements, and a historic preservation or building conservation code if one has been adopted by the jurisdiction. Even on small projects that cannot support a full professional team, consultants should be familiar with historic preservation goals. The State Historic Preservation Office (SHPO) and the local historic preservation office or commission may be able to identify consultants with experience in seismic rehabilitation of historic buildings, or be able to provide initial technical assistance on how to approach a seismic retrofit.

if they have not been previously performed. This evaluation should identify both the potential structural deficiencies of the building (any structural component such as columns, beams, floors, etc., required to resist seismic forces), as well as the potential vulnerabilities of the nonstructural components of the building (all components that are not part of the structural system, which include exterior cladding, glazing, chimneys, interior partitions, ceilings, and other architectural features, as well as building systems, and equipment).

Nonstructural failures generally account for the majority of earthquake damage repair costs during earthquakes. Thus, it is critical to consider the risk and consequences of potential nonstructural failures. This is particularly important for historic buildings located in areas of low or moderate earthquake hazard, where the danger of collapse may be relatively small, but nonstructural elements such as unanchored stone veneers, cornices, parapets, chimneys, and gable ends may dislodge and fall to the ground during a moderate earthquake and pose severe life-safety hazards (Figure 6).

Other important nonstructural hazards to consider are the possibility that gas and water lines may rupture during an earthquake, which can cause fire and water damage. Many of these vulnerabilities can be mitigated by understanding how the forces unleashed in an earthquake affect a building, and then planning and implementing appropriate remedial treatments (Figure 7).

**Factors that influence how and why historic buildings are damaged in an earthquake:**

1. Depth of the earthquake and subsequent strength of earthquake waves reaching the surface
2. Duration of the earthquake, including aftershock tremors
3. Proximity of the building to the earthquake epicenter, although distance is not necessarily a direct relationship
4. Building construction type, including structural systems and materials
5. Building design, including plan and elevation configuration, overall massing, arrangement of interior spaces, and detailing of nonstructural elements
6. Existing building condition, including maintenance level
7. Site and soil conditions

**In the process of assessing the potential seismic risk, these are crucial factors that should be considered:**

1. Type of construction and condition of the building
2. Site seismic hazards
3. Occupancy and use

**Type of Building Construction.** To a great extent, a historic building's construction and materials determine its behavior during an earthquake. Some buildings, such as a broad class of wood-frame structures, are able to absorb substantial movements with little risk of collapse. Others, such as unreinforced masonry or adobe buildings, tend to be more susceptible to damage from shaking (Figure 8). If an earthquake is strong, or continues for a long time, building elements that are poorly attached or unreinforced may collapse or dislodge. Buildings of more rigid or stronger construction methods such as reinforced concrete or steel-frame buildings may also have seismic deficiencies depending on when they were constructed and whether or not they have been well-maintained over time.

A thorough assessment of the building's existing conditions is the basis for any seismic rehabilitation. This begins by gathering any available information about the building's original construction. Many historic buildings in earthquake zones have survived episodes of ground shaking and may even have undergone previous seismic reinforcement work. Compiling any available

documentation that quantifies their proven seismic resistance or describes seismic reinforcement work or any other changes that have occurred over time is extremely useful. Some of these records may have been already compiled in previous documentation assembled to nominate the structure to the National Register of Historic Places or for a Historic Structure Report. (If not previously done, for many buildings preparing a Historic Structure Report is highly recommended; see Preservation Brief 43: *The Preparation and Use of Historic Structure Reports*). Early real estate or insurance maps, such as Sanborn Maps, and assessor's records may also note building changes over time.

Original construction documents, plans and specifications, when available, and engineering drawings, in particular, which include structural layout and connection details are especially useful. When drawings documenting improvements or alterations over time are not available, building permits can also provide useful information. Historic photographs of the building under construction or before and after previous earthquakes are also invaluable. The compiled information, along with a thorough evaluation of the condition and strength of the existing building materials, will provide a sound basis for calculating the potential seismic hazards of the building and preparing a seismic retrofit plan.

**Building Configuration.** The geometry and shape of a building also play a role in how a building behaves during an earthquake. Buildings with regular plans, whether they are round, square, or rectangular, have a greater resistance to damage during an earthquake because their geometry allows for equal resistance of lateral forces in all directions.

Buildings with complex and irregular plans, however, may be more prone to damage during an earthquake because of uneven strength and stiffness. For example, structures with an L, T, H, or other plan configurations with inward-facing, or re-entrant corners, have unequal resistance to stress concentrated at those corners and intersections (Figure 9). This is of particular concern if the buildings have flexible structural systems and/or have an irregular layout of shear walls, which may cause portions of the building to pull apart.

Similarly, the more complex and irregular buildings are in elevation, the more susceptible they are to damage, especially tall structures. Other building features such as large ground-level storefront or garage openings, or floors with columns and walls running in only one direction, are commonly known as "soft" or "weak" stories, which increase the seismic vulnerability of historic buildings (Figures 10 and 11).

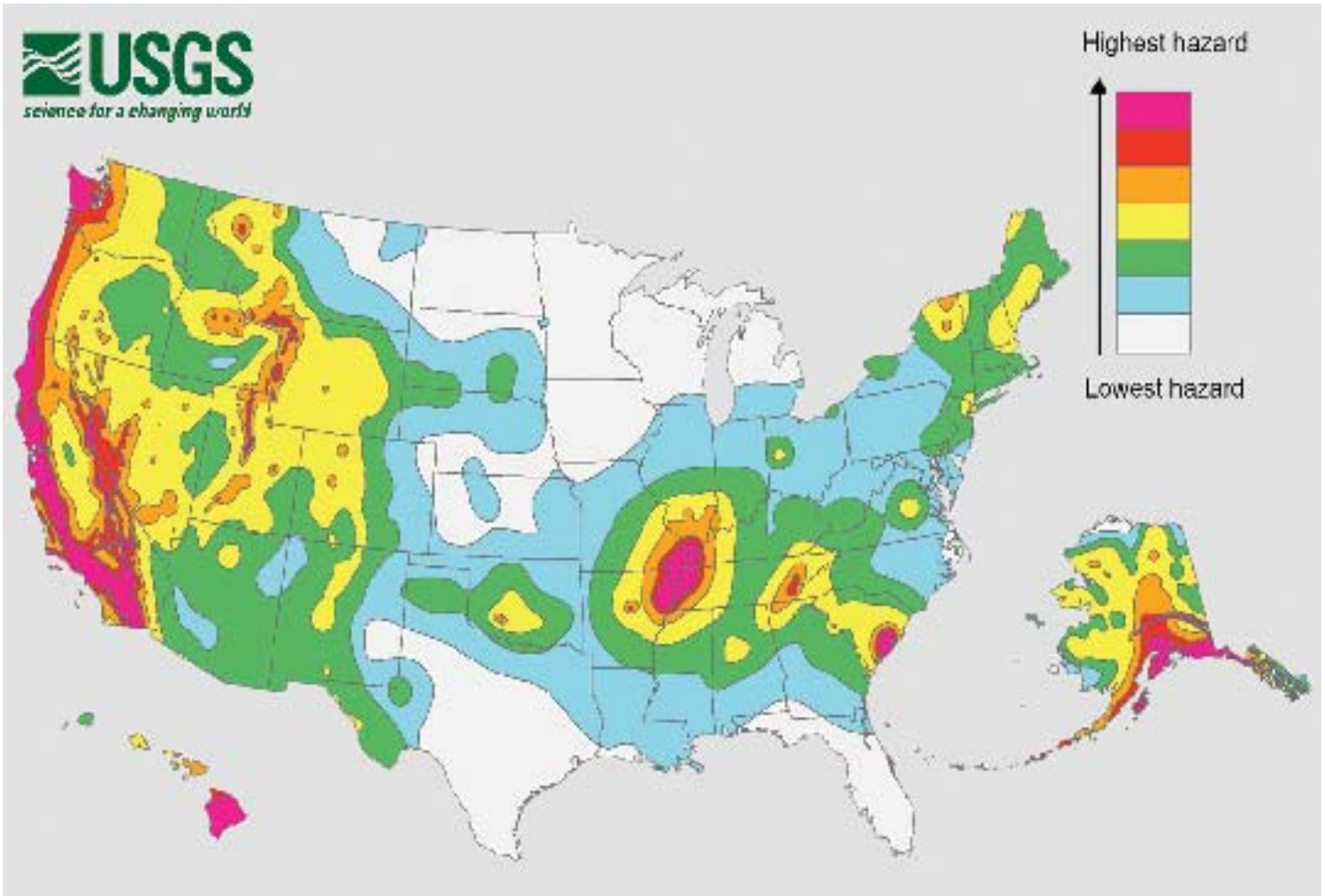


Figure 7. A simplified 2014 United States Geological Survey (USGS) seismic hazard map. Owners of certain classes of high-risk buildings in regions of high seismic activity are advised, and often required by local ordinances, to take immediate action in undertaking a comprehensive vulnerability assessment and make any necessary seismic rehabilitation measures. Owners of buildings in moderate seismic zones are advised to do further investigation of their building's exposure to earthquake risk, identify seismic rehabilitation needs, and consider mitigation of risks primarily due to nonstructural hazards. Owners of buildings in low seismic areas are advised to consider low-cost rehabilitation measures that protect against casualties and property loss, if such measures are found to be necessary, even though the potential occurrence of an earthquake might be low.



Figure 6. Failing nonstructural elements such as the stone-veneer window and door surrounds shown in this image can become a life-safety hazard when they block or impede an exit path. Photo: Wiss, Janney, Elstner and Associates, Inc.

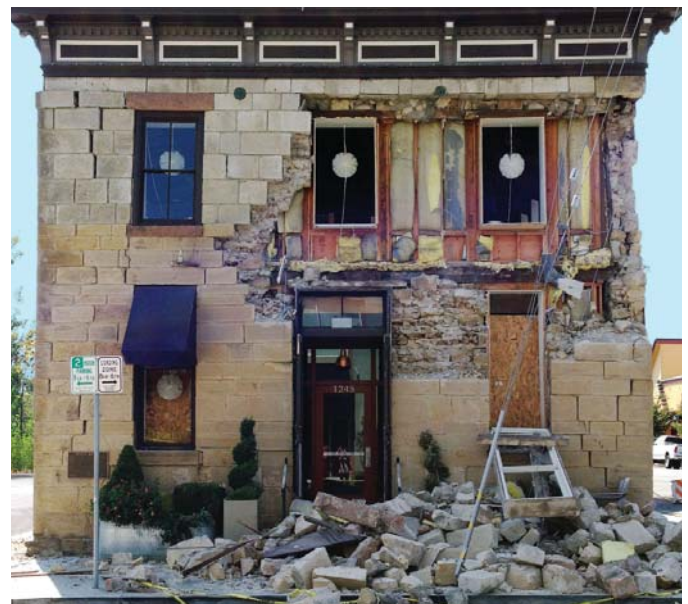


Figure 8. Unreinforced masonry buildings, such as this 1875 stone building damaged during the 2014 South Napa, California earthquake, can be particularly vulnerable to earthquake damage. Photo: Architectural Resources Group.

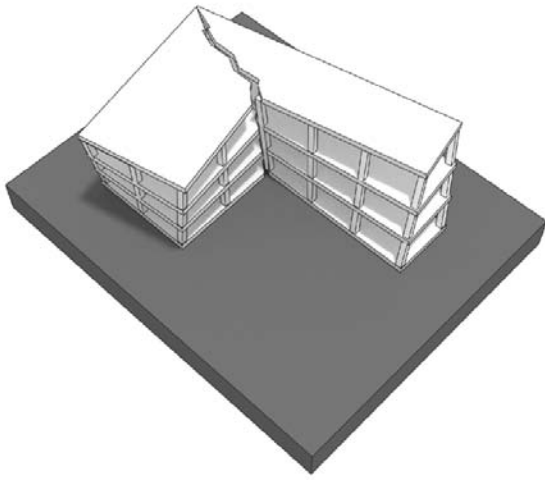


Figure 9. This image shows structural deformation due to stress concentration in structures with re-entrant corners, the inside corner where the two perpendicular exterior walls meet.

**Building Condition.** Damaged and deteriorated building materials increase the risk of serious damage during an earthquake. This condition can be the result of poor quality workmanship and materials from when the building was built, or lack of proper maintenance. Material damage and degradation due to moisture, erosion, mold, or insect infestation are typical problems resulting from poor maintenance. Well-maintained buildings, even without added reinforcement, survive better than similar buildings that have not been maintained. In unreinforced masonry buildings, deteriorated mortar joints can weaken entire walls. Regular cyclical maintenance is therefore essential.

The capacity of the structural system to resist earthquakes may also be severely reduced if previous alterations or earthquakes have weakened structural connections. Unrepaired cracks or damage from previous earthquakes can progressively weaken a building, increasing the potential for greater damage during the next earthquake. Cumulative earthquake damage can be significant; therefore, it is important to analyze the structural capacity of the building.

Over time, structural members can become loose and pose a major liability. Unreinforced masonry buildings typically have a friction-fit connection between horizontal and vertical structural members, and the shaking caused by an earthquake pulls them apart. Insufficient bearing surfaces for beams, joists, and rafters against the load-bearing walls or support columns is another important factor to consider. The resulting structural inadequacy can cause a partial or complete building collapse,

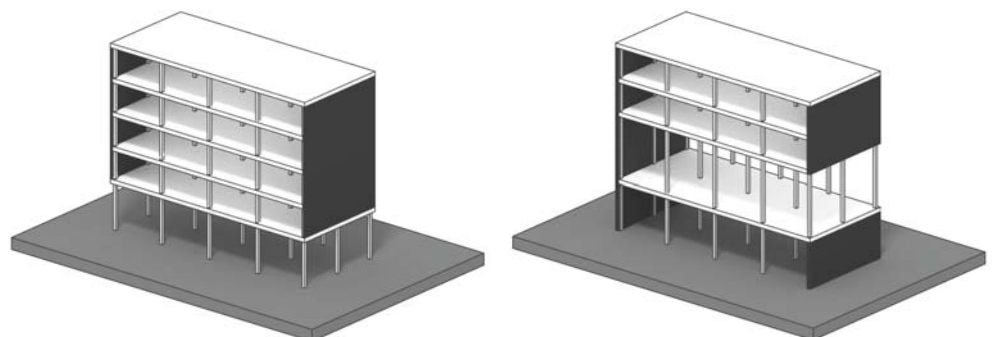


Figure 10. (left) Open first floor. Figure 11. (right) Double height second floor. These renderings show examples of “weak” or “soft” story irregularities.

## Basic Maintenance/Earthquake Preparedness

Regular maintenance ensures that existing historic materials remain in good condition and are not weakened by rot, rust, decay, or other moisture problems. Without exception, historic buildings should be well maintained. An evacuation plan should also be developed. With the knowledge that an earthquake may occur at any time in the future, building owners should have emergency information and supplies on hand.

- Check roofs, gutters, and foundations for moisture problems, and check for corrosion of metal ties at parapets and chimneys. Make repairs and keep metal painted and in good condition.
- Inspect and keep termite and wood-boring insects away from wooden structural members.
- Check exit steps and porches to ensure that they are tightly connected and will not collapse during an emergency exit.
- Check masonry for deteriorating mortar, and never defer repairs. Repoint, matching the historic mortar in composition and detailing.
- Contact utility companies for information on flexible connectors for gas and water lines and earthquake-activated gas shut-off valves. Strap oil tanks down and anchor water heaters to wall framing.
- Collect local emergency material for reference and implement simple household or office mitigation measures, such as installing latches to keep cabinets from flying open or braces to attach tall bookcases to walls. Keep drinking water, tarpaulins, and other emergency supplies on hand.

depending on the severity of the earthquake and the internal wall configuration.

Evaluation of the general physical condition of the building's interior and exterior, and identification of areas vulnerable to seismic damage, often requires testing and analysis to determine the durability and strength of materials and structure. This should be performed by a qualified engineer who is knowledgeable of historic materials and construction methods. In order to evaluate the actual strength and condition of the historic materials, selective destructive testing may be required.

**Site Seismic Hazards.** In addition to the shaking motion of the ground during an earthquake, there is risk of damage due to site-specific hazards, such as fault rupture; liquefaction and other soil failures; landslides; hazards from adjacent buildings, including pounding; or potential inundation from nearby dam failure or a tsunami. If such hazards exist, they should be addressed along with any needed seismic rehabilitation of the building.

**Occupancy and Use.** A building's occupancy and use have a direct relationship to its seismic risk, as well as the social, economic, or environmental consequences that an earthquake may pose. From a life-safety perspective, warehouses, barns, and certain industrial buildings and structures with low human occupancy may present a lower risk compared to high-rise office buildings, theaters, and other high-occupancy buildings. Specific uses such as medical facilities, housing for persons of limited mobility, or buildings that support vital community services or utilities fall within use categories where the risk of damage or collapse during an earthquake requires special consideration. Owners of historic buildings that are being repurposed for a new use should be aware that, depending on the change, the new use may pose a higher risk to life safety and may require significant seismic reinforcement to mitigate its seismic risk. Inversely, if the change in use lowers the risk to life safety, the need for extensive seismic retrofit work may not be necessary.

## Evaluating Significant Historic Features and Spaces

Just as important as the assessment of the material and structural condition of a building is the careful identification of the interior and exterior features and components that help define its historic character. Establishing a protection and preservation plan that identifies significant interior spaces, features, and finishes is essential. Significant architectural elements include domes and atriums and important or highly-decorative features such as staircases, ornate ceilings, mosaics, murals, and other historic treatments.



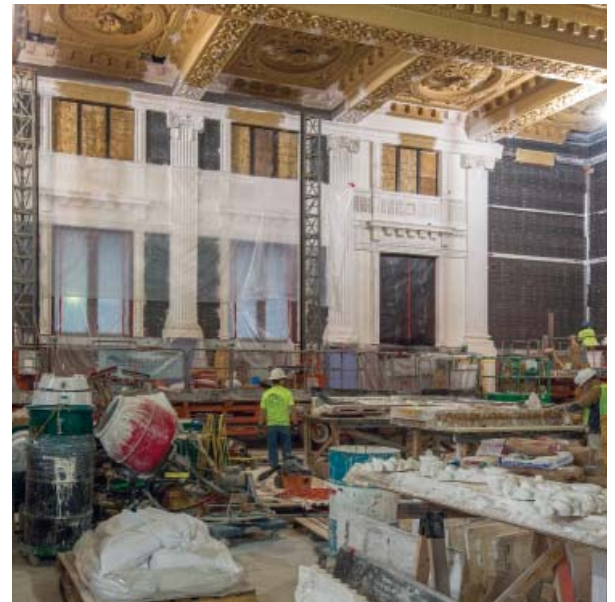
Figure 12. A mezzanine was added to the original banking hall of this 1921 former bank building as a seismic strengthening measure. Subdividing such an important character-defining space can result in a severe loss to a building's historic integrity.

Conversely, it is also important to identify secondary or tertiary areas of the building, or any spaces, features, or finishes that have been changed over time and no longer have historic significance. Less important spaces may provide areas for additional structural reinforcement to be installed during a seismic rehabilitation without having an adverse impact on the overall historic character of the building.

The placement of additional structural reinforcement should be carefully considered to avoid or appreciably minimize any impact on the building's significant or primary exterior and interior spaces (Figure 12). New structural elements should be located within interstitial or utilitarian spaces whenever possible. Alterations within secondary spaces are preferable to alterations of primary spaces, but care should be taken to preserve historic materials and character to the greatest extent feasible in these areas as well. When new structural elements must be added within significant interior spaces, the placement and location should avoid major alterations to the overall volume, distinctive architectural features, or finishes within the space, as well as to its character (Figures 13-15). (See *Preservation Brief 17: Architectural Character—Identifying the Visual Aspects of Historic Buildings as an Aid to Preserving their Character*, and *Preservation Brief 18: Rehabilitating Interiors in Historic Buildings: Identifying and Preserving Character-Defining Elements*.)

## Developing a Seismic Rehabilitation Plan

**Seismic Vulnerability.** Seismic vulnerability is represented as a sliding scale of potential damage based on the probability of hazard by locale (site-specific data) and building use. This helps the owner understand the building's vulnerability to damage, both structural and nonstructural, in the event of an earthquake. Consequences of earthquake vulnerability may be characterized as:



Figures 13-14. Vertical steel reinforcement members were inserted and grouted into the walls of the main waiting room in Seattle's historic 1906 King Street Railroad Station to strengthen them (top left). To replace the original plaster ornamentation, molds were made to cast new replacement plaster elements as shown on this work-in-progress photo (top right). Photos: John Stamets.



Figure 15. After completion of the seismic reinforcement, the replicated plaster ornamentation was installed and the decorative painted finishes restored, returning the waiting room of King Street Station to its historic appearance. Photo: Doug Scott.

- Deaths and injuries to building occupants and related liability
- Building collapse or damage to building components, and related cost for repairs
- Damage to building contents and related cost or liabilities
- Disruption of building operations and related cost or liabilities

**Performance Objectives.** Once the risks and vulnerabilities of a building have been assessed, the next step in the process is usually setting goals for reducing the seismic risks. Knowing what rehabilitation requirements are mandated by the local jurisdiction is critical, as well as knowing whether a locality has separate codes for historic structures. There may be other triggers, such as a lender requiring retrofit or earthquake insurance when refinancing a loan, or a change of occupancy. The owner should also be aware

of the different levels of seismic risk-reduction measures that can be chosen and their associated cost. Alternative ways of reducing seismic risk to life and property, such as reducing the occupancy of a building or providing alternative facilities in case of an earthquake, should be studied.

After all alternatives have been considered, modification options for reducing the risk of damage to a historic building should be evaluated. Before undertaking a seismic rehabilitation, objectives that define the level of acceptable damage or loss for a building during a potential earthquake must be determined. These are referred to as "rehabilitation objectives." The rehabilitation objectives are usually set by the local code, ordinance, or code official in mandatory seismic strengthening programs, or chosen by the owner and engineer in a voluntary seismic rehabilitation (see ASCE Standard 41-13).



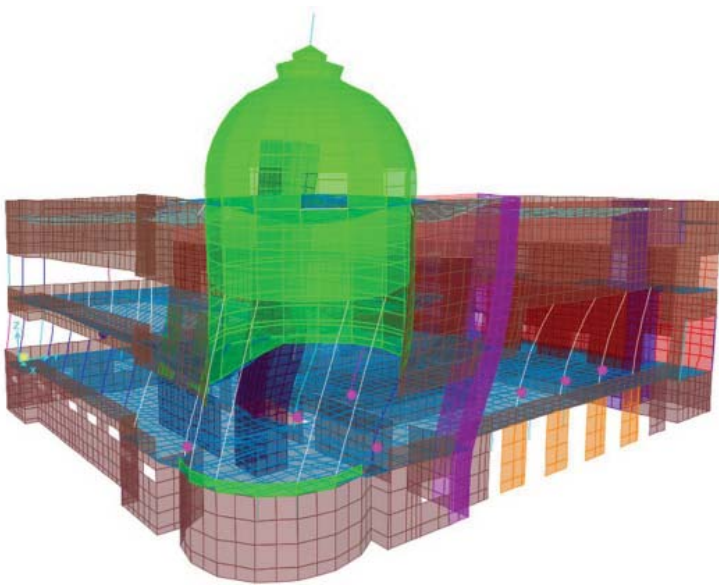


Figure 16. Computer modelling is a useful analytic tool that helps assess the strengths and weaknesses of a building and evaluate different seismic strengthening options. Three-dimensional dynamic analysis is required for a number of different structures located in certain seismic zones.

Photo: Wiss, Janney, Elstner and Associates, Inc.

The rehabilitation objectives are based on target “building performance levels” which provide a limiting range to the amount of predicted damage that a building should sustain during an earthquake. Building performance levels fall into four general classifications that rank from higher performance (lower risk) to lower performance (more risk):

1. **Operational.** Backup utility services maintain function; the building sustains very little damage. This approach is intended for critical facilities, such as hospitals and emergency management centers, which must remain open and operational after a major earthquake. For some historic buildings, achieving this level of performance may be difficult or next to impossible without a great deal of modification. However, as more buildings that were engineered to sustain ground-shaking become historic, more may achieve this level of performance.
2. **Immediate Occupancy.** The building remains safe to occupy. Damage and expected repairs are minor.
3. **Life Safety.** The building remains stable and has substantial structural reserve capacity; hazardous nonstructural damage is controlled.
4. **Collapse Prevention.** This addresses the most serious life-safety concerns by correcting those deficiencies that could lead to serious human injury or total building collapse. The building remains standing in order for occupants to exit the building; any other damage or loss is acceptable. It is expected that if an earthquake were to occur, the building should not collapse but would be seriously damaged, could not be occupied, and would require major repairs or need to be demolished.

From a design perspective, the vast majority of historic buildings can tolerate a well-planned and placed system of seismic reinforcement. Utilitarian structures, such as warehouses, may be able to receive fairly visible reinforcement systems without undue damage to their historic character (Figures 17-18). Other, more architecturally detailed buildings or those with more finished or decorative interior surfaces will benefit from more hidden systems. However, installation of such systems may require the temporary removal and reinstallation of significant features as part of the seismic rehabilitation work. Most buildings can incorporate



Figures 17 and 18. Careful placement of the new structural reinforcement, painted to match the surrounding building elements, if left exposed, minimizes its visual impact. New added structural elements may be left exposed when their visibility does not impair the historic character of the building. Figure 17 (left). Photo: Jason Hagin. Figure 18 (right). Photo: Architectural Resources Group.

seismic hazard mitigation during other construction work in a way that ensures a high degree of in-place retention of historic materials.

Building performance levels are established for both structural and nonstructural damage. While reducing life-safety risks and ensuring safe post-earthquake occupancy of a building might be the primary concerns for many owners, potential damage to contents may be extremely important in certain circumstances. Important archives and records, invaluable art objects, and book and other collections are often housed in historic buildings. Risk-reduction measures associated with hazardous materials or valuable equipment must also be considered.



Figure 19. Chimneys are common nonstructural features susceptible to earthquake damage, even in zones of low-to medium-seismic activity as shown on this building in Virginia damaged in a 2011 earthquake. Photo: Suzanne Tripp.

## Hazard Mitigation of Nonstructural Components

Nonstructural components are all those elements other than the columns, bearing walls, floors, beams or trusses, bracing elements, foundation, and other elements that make up a building’s structure (Figures 19-20). In the past, seismic rehabilitation of existing buildings has focused on mitigating structural deficiencies. However, nonstructural components represent a substantial portion of a building’s initial capital investment; and, based on post-earthquake surveys, losses from nonstructural components also represent a high percentage of losses during an earthquake (see FEMA E-74: *Reducing the Risk of Nonstructural Earthquake Damage—A Practical Guide*).

Similar to structural components, a risk assessment of nonstructural components should be completed based on the hazards they present. The potential consequences of earthquake damage to nonstructural components depend on the type of risk they pose:

**Life Safety.** Could anyone be hurt by this component in an earthquake?

**Property Loss.** Could a large property loss result?

**Functional Loss.** Could the loss of this component cause an outage or interruption in operations?

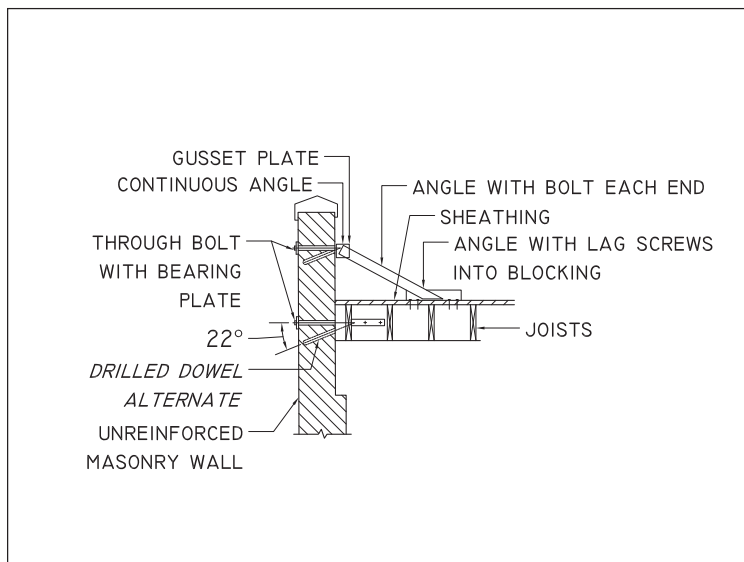


Figure 20. Bracing parapet walls, as illustrated in the typical detail drawing on the left, and as installed in the image on the right, helps avoid hazards from falling debris.

## Hazardous Nonstructural Components

The following list represents typical components and is not exhaustive:

### Architectural

- Exterior walls (including masonry veneers, prefabricated panels, glazing, glass block, and curtain wall and storefront window systems)
- Partitions (hollow- clay tile, unreinforced masonry, or similar)
- Ceilings (plaster or other heavy material, particularly if suspended)
- Parapets, cornices, turrets, and other projecting decorative elements (unreinforced masonry)
- Balconies, canopies, marquees, and signs
- Chimneys and exhaust/ vent stacks (unreinforced masonry)
- Stairways

### Mechanical, Electrical, and Plumbing Systems

- Boilers, furnaces, pumps, and chillers
- Water and fuel storage tanks
- Plumbing and piping, both nonhazardous and hazardous materials, including sprinkler systems
- Conduits
- Ductwork
- Light fixtures
- Electrical and communication equipment

### Furnishings and Interior Equipment

- Storage racks
- Bookcases
- Filing cabinets
- Hazardous material storage units
- Elevators
- Conveyors
- Other contents in museums and historic houses

## Cost and Implementation

Designing a successful seismic rehabilitation takes into consideration not only seismic performance and historic preservation concerns, but financial ones as well. The rehabilitation of historic buildings often triggers mandated seismic strengthening work to comply with local codes. This often occurs when the amount of work crosses a certain threshold or when the rehabilitation involves a change in use, such as the conversion of an industrial building into a residential use. In these cases, the rehabilitation includes all the work necessary to meet the new programmatic requirements as well as the seismic performance objectives in a “single-stage” project. All the costs and occupancy disruptions are also incurred at one time, and a significant upfront capital investment is required.

When budgetary constraints and/or occupancy restrictions do not make a single-stage project feasible, a “multi-stage” project that spreads the cost and occupancy disruptions over a set period of time should be considered. The term used for a planned rehabilitation, implemented over a period of time to meet a predetermined seismic performance objective, is an “incremental rehabilitation.” In an incremental rehabilitation, the work is integrated into ongoing facility maintenance and capital improvement operations. An incremental approach has been shown to have many advantages from a benefit/cost analysis (see FEMA 227, 395, and 399).

### Preparation of Construction Documents and Execution of the Work

Whether the seismic rehabilitation will be done as a single project or incrementally, construction documents must be prepared. The documents should clearly define the overall scope of the work. In the case of an incremental rehabilitation, the scope and sequence of each phase must also be clearly detailed. A good set of construction documents along with a quality assurance program to ensure that the design is carried out as specified is critical for any successful seismic rehabilitation. It is also critical that the construction documents include details and specifications for the treatment of historic features and materials. Selecting a contractor with a proven record of successful historic rehabilitation work is extremely important. It is also recommended that the project team schedule a meeting with the local building code official to discuss the seismic retrofit approach and to explore potential code compliance alternatives.

## Questions to Ask

These questions should be discussed with the team to determine acceptable alternatives. Since there is never a single “right” answer, the design team and code officials should work together to determine the appropriate level of seismic retrofit with the lowest visual impact on significant spaces, features, and finishes on both the interior and exterior of historic buildings. This guide is not intended to prescribe how seismic retrofit should be done, but rather, to illustrate that every physical change to a building will have some consequence. By asking how impacts can be reduced, the owner will have several options from which to choose.

- Can bracing be installed without damaging decorative details or the appearance of parapets, chimneys, or balconies?
- Are the visible features of the reinforcement, such as anchor plates/washers or added exterior buttresses adequately designed to blend in with the historic building?
- Can hidden or grouted bolts be used to tie floors and walls together, instead of using traditional bolts and exposed washers or rosettes if they might detract from a building’s historic character?
- Are diagonal frames, such as X- or K-braces or other located to have a minimal impact on the primary facade? Are they set back and painted a receding color if visible through windows or storefronts?
- Can moment frames or reinforced bracing be added around historic storefronts in order to avoid exposed reinforcement, such as X-braces, within the immediate viewing range of the public?
- Can shorter sections of reinforcement be “stitched” into the existing building to avoid removing or covering large sections of historic materials? This is particularly important for the insertion of additional roof framing supports.
- Can shear walls be located in utilitarian interior spaces to reduce the impact on finishes in the primary areas?
- Are there situations where a thinner, applied fiber-reinforced coating would adequately strengthen walls or supports without the need for heavier reinforced concrete?
- Can diaphragms be added to non-significant floors in order to protect highly decorated ceilings below, or the reverse if the floor is more ornamental than the ceiling?
- Are there adequate funds to retain, repair, or reinstall ornamental features and finishes once structural reinforcements have been installed?
- Should alternative seismic reinforcement methods such as base isolation, wall damping systems, or core drilling be considered? Could they protect significant features and materials by reducing the amount of intervention required?
- Are the seismic treatments under consideration “reversible” in a way that allows the most amount of historic materials to be retained and allows future repair and restoration?
- Could the seismic rehabilitation add excessive strengthening that could have unintended negative consequences to the historic structure during an earthquake?

## Remediating Seismic Deficiencies

Achieving desired building performance objectives depends on the specific occupant needs, site, and building conditions. The particular approaches to achieving this should also be tailored to the unique historic character and conditions of each building, and the specific seismic deficiencies that need to be remedied or mitigated. Most seismic deficiencies and possible required mitigation techniques can be divided into the general categories described here. Although not an exhaustive list, it is intended to provide an overview of the scope of work a building owner or project manager might expect during a seismic rehabilitation.

**Inadequate Global Strength or Stiffness.** Historic buildings which were not designed to resist the lateral forces of a ground-shaking event often lack adequate overall strength, or “global strength.” While this is seldom the only deficiency that needs to be mitigated, lack of sufficient global strength makes a building particularly vulnerable during a seismic event.

Approaches to mitigating this deficiency often require reinforcing the existing structure or adding structural components to strengthen the building. Mitigating the lack of sufficient overall stiffness, or “global stiffness,” is also necessary in many seismic rehabilitations. While the methods used to improve stiffness are often the same as those used to correct inadequate strength, strength and stiffness are considered separately because they relate to specific building responses. A building may have minimum acceptable strength to prevent its collapse, but if it is too flexible the building may be vulnerable to excessive movement or drift. Too much drift often results in extensive damage to exterior and interior walls and nonstructural components.

The addition of steel moment frames, braced frames of various configurations, and concrete shear walls are typical methods for increasing the strength and stiffness of a building. Careful placement of new structural elements is critical to avoid negatively affecting windows and doorways, particularly on highly-visible elevations. Alterations to significant interior spaces such

as lobbies, assembly spaces, and other character-defining spaces should likewise be avoided.

**Building Irregularities.** Plan irregularities such as re-entrant corners place extraordinary demands on building elements due to torsional or twisting reactions to the ground-shaking forces of an earthquake. Vertical irregularities create an uneven distribution of the mass or stiffness between the vertical elements of the building which can be particularly problematic in multi-story buildings. The vulnerability to seismic damage that these types of irregularities impose was seldom considered in the original design of many historic buildings, and normally requires retrofit measures to mitigate them.

Plan and elevation irregularities are too many to enumerate here. Mitigation measures for this type of deficiency can be challenging to undertake in historic buildings, as some of these irregularities may be important to the building's historic character. Some of the most problematic solutions involve adding shear walls directly behind window and door openings, particularly when they are on highly-visible elevations. Solutions that involve inserting a new floor or a large mezzanine into an architecturally significant, two-story space should be avoided.

**Load Path.** There should be a positive and continuous load path to convey lateral forces. Inadequate connection between structural and nonstructural components of a building is one of the most critical deficiencies to be addressed in many seismic rehabilitations. Forces acting on building components must be able to be transferred down to the supporting soil. For example, in order to resist the forces of an earthquake, a panel of cladding must be adequately connected to the floor, walls, frames, braces, and other structural members that connect it to the building's foundation.

A strong connection between all of the elements of the building allows for the transfer of the stressing forces down to the foundation, where it is absorbed by the soil. Breaks or failures along this load path render any existing seismic system ineffective. Methods for mitigating load path deficiencies range from simple reinforcement measures such as adding metal straps, threaded bolts, and other mechanical fasteners to more elaborate engineered connections. Adequate connections between walls, roof, floors, and foundation are critical, as well as between the components of all the vertical and horizontal structural components of the building such as joist to beams or walls, and columns to beams and floors or footings.

**Diaphragms.** Floors and roofs are commonly referred to as "diaphragms" in seismic design. Diaphragms act as horizontal "beams" between the vertical elements (walls and/or columns) that resist the lateral forces during an earthquake. Inadequate shear, bending strength,

and stiffness are some of the most common diaphragm deficiencies. Strengthening methods for diaphragms can entail adding sheathing to roofs or floors, installing tension rods in shallow-vaulted concrete floors, and various other methods.

Reinforcement around openings, re-entrant corners, and mitigation of other plan irregularities may also be necessary. Ensuring proper transfer of the lateral earthquake forces spread over the diaphragm to the lateral force-resisting system (vertical elements of the structure) is also an important component of a seismic retrofit. Adequate diaphragm "collectors," structural elements that collect the lateral force and transfer it to the lateral force-resisting system, need to be strengthened or added to compensate for any deficiencies in the existing construction.

**Foundations.** Foundation deficiencies can vary greatly and include deficiencies within the foundation system itself or with the soil conditions. Foundation deficiencies are independent of building or construction type, and remedial work can include replacing or upgrading the existing foundation, adding a new foundation next to the existing one, or adding new pilings or drilled piers. While often expensive and disruptive to correct or mitigate, foundation deficiencies are critical to address.

## Remediating Seismic Deficiencies According to Building Construction Type

**Unreinforced Masonry Bearing Wall.** Unreinforced masonry (URM) buildings are most commonly brick or stone without steel reinforcement bars imbedded in them. In many historic buildings of this type, masonry bearing walls support the weight of the roof and floors. Joists bear directly on the wall at the perimeter of the building and are supported by post and beams on the interior. Unreinforced masonry is one of the oldest and most diverse construction types and encompasses a wide range of materials and wall construction methods such as solid clay brick, cut or field stone, hollow-clay brick, structural tile, concrete masonry units, and adobe.

URM buildings are generally considered to be some of the most susceptible to earthquake damage. In strong earthquakes, the walls may fall outward and cause a partial or total collapse of the building. Poor connection between the exterior walls and diaphragms severely impair the capacity of a URM building to resist an earthquake, and thus it is important that this be remediated. Other significant hazards that can be life threatening are falling debris from parapets, cornices, chimneys, or other nonstructural elements.

A basic seismic rehabilitation program for a URM building may involve bracing the parapets and chimneys, and securing other elements that can break away from the building, as well as securing the walls to the floors and roof. Engineering analysis of the structure



Figure 21 Historic wine cellar building in Napa, California.

Figure 22. Drawing of the wine cellar's front wall showing the locations of the center cores for continuous steel reinforcement rods to be inserted and grouted in place.

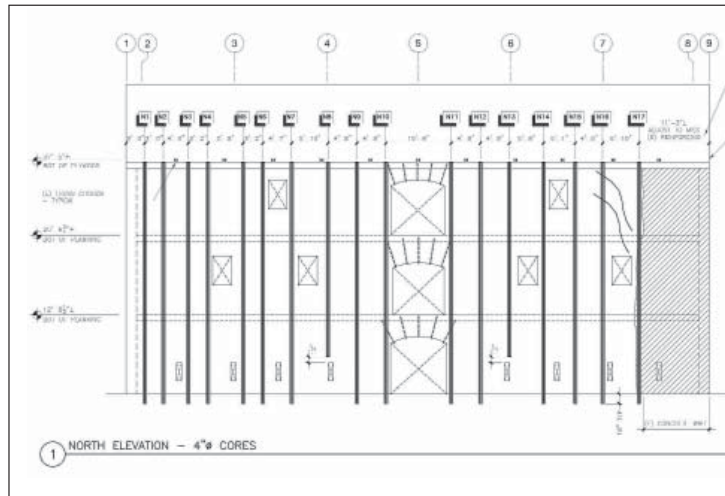


Figure 23. View of one of the center cores drilled down through the wall.



Figure 24. Eye bolts used to anchor the floor to the wall.



Figure 25. Location of the eye bolts after grouting

The seismic rehabilitation of this historic wine cellar building shown in Figure 21 included center coring of the exterior stone walls to add steel reinforcement, as illustrated in Figures 22 and 23. The floors were tied to the steel reinforcement in the walls using eye bolts, as seen in Figures 24 and 25, eliminating the need for exterior washers or plates. Figure 21. Photo: Architectural Resources Group. Figures 22-25. Photos: MKM & Associates.

may indicate that additional reinforcement of the roof and floor may be necessary. This may be accomplished by adding columns or shear walls in order to adequately transfer lateral loads to the ground.

Preventing the collapse of the walls, particularly load-bearing walls, is critical in URM buildings. This entails strengthening the walls through various methods such as adding strongbacks, or secondary support members, to the wall; adding a layer of steel-reinforced concrete; adding shotcrete bonded to the URM wall; core drilling; or adding a fiber composite layer (epoxy embedded fiberglass mesh). Adding interior wall bracing or inserting vertical steel bars embedded in grout into the wall itself are also widely-used wall reinforcement methods. These techniques must be carefully evaluated to balance building performance and preservation objectives (Figures 21-27).

**Concrete Frame.** Most historic concrete building assemblies consist of concrete columns and floor

systems of various types (flat slabs, two-way slabs, and beam-and-slab). Exterior and interior walls are often unreinforced masonry, commonly called infill, and are typically nonstructural, presenting the deficiencies described previously. The most important structural vulnerability of this construction type is the lack of ductility. Prior to 1960, building codes may not have required concrete-frame buildings to be designed and detailed for ductile performance (i.e., not fail when loaded beyond capacity) to resist lateral forces, depending on the region. Concrete-frame buildings were required to be “ductile” in the 1976 Uniform Building Code. In many historic concrete-frame buildings, because the connection between the columns and beams is not strong enough to resist the lateral loads during an earthquake, the buildings are in danger of collapsing. Particularly vulnerable buildings of this type are those with relatively few concrete walls and columns that are weaker than the beams or slabs. Mitigating this condition is typically accomplished by adding a new system, such as shear walls (Figure 28).



Figure 26. Epoxy-embedded fiberglass mesh is being bonded to the back of the brick pilasters of this 1906 unreinforced masonry building. New finishes matching the appearance and detailing of the original finishes will be applied over the mesh. Photo: Wiss, Janney, Elstner and Associates, Inc.

Figure 27. A new steel stud wall is being added to one side of this interior hollow-clay tile wall. The side with the least amount of historic finishes was chosen as the least disruptive location for the added reinforcement. The wall will be returned to its original appearance by installing new finishes matching the historic finishes. Photo: Wiss, Janney, Elstner and Associates, Inc.





Figure 28. Steel reinforcement for the new shear walls, perpendicular to the windows, is being installed in this concrete-frame building.  
Photo: Robert Chattel.

**Steel Frame.** This type of construction consists of a complete frame of steel columns and beams. Floors are usually concrete slabs or metal decks filled with concrete. Exterior walls can be reinforced or unreinforced masonry, architectural terra cotta, glass curtain walls, or other types of construction. Mitigating the seismic deficiencies of the nonstructural elements must be done according to their construction methods. Steel-frame construction is used in a wide variety of building types such as offices, hospitals, government, and academic buildings, as well as industrial and other utilitarian structures. This type of construction started to gain widespread use in the latter part of the 19th century.

There are two general categories of steel-frame construction: Steel **moment frame**, which consists of steel columns and beams with rigid connections using angles and plates that can be riveted, welded, or bolted together; and **braced frame**. Braced-frame structures have diagonal steel members placed in selected bays of the structure to improve the lateral force resistance of the overall structure, whereas moment frames rely on the strength of rigid corner connections to resist lateral forces.

Steel-frame buildings, particularly braced-frame buildings, have superior seismic performance over other construction methods. Moment-frame buildings are very elastic during seismic activity, and, although they are

able to withstand strong lateral forces, they are subject to significant movement between stories, or interstory drifts, and are also prone to pounding on adjacent buildings. Their flexibility can also result in damage to structural connections as well as to interior walls and cladding.

Large interstory drifts may make steel-frame buildings more difficult to repair after an earthquake. Typical remedies to improve the stiffness of steel-frame buildings include adding new concrete shear walls or brace frames, or adding steel cover plates to the existing steel columns. The latter technique may not be recommended if it requires significant removal or damage to existing historic features or finishes.

**Light Wood Frame.** Light wood-frame construction is common in much residential and small commercial building construction. It includes both post-and-beam construction as well as stud-wall construction. Life-safety performance of light wood-frame construction during an earthquake is typically very good. The most common seismic deficiency of this building type is the lack of, or poor, anchorage of the walls to the foundation, deterioration of existing structural fasteners, and/or an insufficient number of fastened connections. Inadequate strength of the lower stories in multi-story buildings may also be a vulnerability. In many dwellings this includes structures resting on intermittent wood or masonry piers, unfinished garages, and/or crawlspaces.



Unbraced cripple walls and poor foundation anchorage are common vulnerabilities in many one-and two-family detached dwellings of one or more stories. In these buildings, interior walls usually provide sufficient bracing to resist lateral loads during a seismic event, but the crawlspace often only has perimeter framing which may become highly stressed and collapse during an earthquake. Adequate anchorage to the foundation in wood-frame dwellings prevents them from sliding off their foundation. Mitigating the lack of adequate bracing of cripple walls and proper foundation anchoring are high priority seismic rehabilitation measures in light wood-frame buildings (Figure 29).

Multi-story, multi-unit residential wood-frame buildings with parking, common areas, or commercial uses on the ground floor are a sub-category of this construction

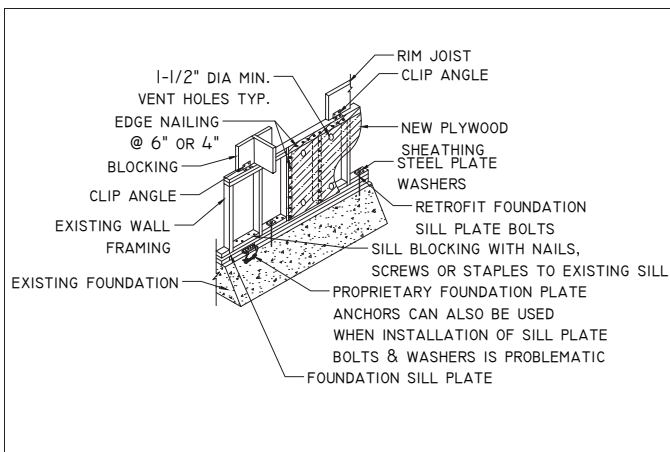


Figure 29. Cripple-wall reinforcement. Simple approaches such as nailing plywood between crawlspace studs, bolting sill plates to the foundation, and strapping the cripple wall to the floor above can make a dramatic difference in protecting a building from seismic damage.



Figure 30. Large perimeter openings and a limited number of interior partitions on the ground floor can create a “weak story” condition that makes buildings particularly vulnerable to earthquake damage. Photo: USGS.

type that is also very susceptible to damage during earthquakes. The upper floors of these buildings typically have a repetitive interior layout which gives them uniform strength and stiffness. The lower floors however, because they typically have larger exterior openings and may have more varied interior configurations and large open spaces, often create a “weak story” condition (Figure 30).

Seismic rehabilitation requirements for one-and two-family residential and other small-scale buildings commonly include securing chimneys and correcting other life-safety nonstructural deficiencies, such as bolting the sill plate to the foundation and adding plywood sheathing to reinforce knee walls. Structures built over intermittent wood or masonry piers are also vulnerable during earthquakes. Providing connection between the piers or installing a new continuous support element of adequate strength under the walls is often required. Large exterior openings such as garage doors or structural irregularities such as cantilevers must also be evaluated and mitigated. In the case of multi-story apartment buildings with a soft or weak story, additional steel frames or masonry shear walls may be necessary to give adequate strength to the ground floor (see FEMA P-807).

## Seismic Isolation and Energy Dissipation Systems

Seismic isolation and energy dissipation systems are relatively new, highly sophisticated methods that require extensive design and engineering analysis. Seismic isolation systems involve disconnecting, or greatly reducing, the transmission of the seismic forces from the ground to the building. Energy dissipation methods involve either passive or active energy dissipation devices that dampen the effects of the lateral and vertical motion of an earthquake. Energy dissipation systems are sometimes used in tall buildings where installing seismic isolation systems may not be feasible. However, implementing either of these systems is often too costly or impractical for most seismic rehabilitations of historic buildings.

## Important Preservation Considerations

Reinforcing the connection between various structural and nonstructural elements, installing new structural elements, and performing other seismic rehabilitation work may require selective removal of historic wall and ceiling finishes. Attention should be given to minimize the amount of historic material removed, as well as performing the necessary repair or replacement of the historic features and finishes after the seismic work is completed.

Completely removing a character-defining feature such as a chimney, cornice, or parapet in order to mitigate its

seismic vulnerability is not a recommended treatment. Instead, such building elements should be braced and secured whenever possible. If a significant architectural feature has sustained earthquake damage, it should be repaired rather than removed. If the damage is so extensive that it requires complete replacement, using in-kind replacement materials is generally the recommended approach. In some circumstances, however, a compatible substitute material that meets technical performance requirements may be appropriate, such as a lighter weight material that matches the original in design and appearance.

Historic corridor walls constructed of unreinforced masonry, hollow-clay tile in particular, need careful consideration. Every effort should be made to retain the historic materials while taking measures to secure the wall and the historic materials to prevent them from the possibility of injuring occupants or blocking an egress path. Every available reinforcement method and technique that allows the corridor walls and their historic materials and detailing to be preserved in place should be considered. If retention of the core masonry elements is not feasible, but there are extant features and finishes, such as a marble wainscot, doors and transoms, wood trim, or other features, they should be retained, even if they have to be reinstalled over a new framing structure for the corridor that replicates the ceiling height, corridor width, and the relationship and installation details of the historic features.

## Post-Earthquake Issues

In most municipalities, a survey or inspection, usually by professionals or trained volunteers, will be conducted as soon as possible after an earthquake, and buildings will be tagged on the front with a posted notice stating whether they are safe to enter. Typically red, yellow, and green tags are used to indicate varying levels of damage—no entry, limited entry, and useable, respectively—and their relative safety. Heavily-damaged areas are often secured and determined off-limits, and, unfortunately, many red-tagged, but repairable, buildings have been torn down unnecessarily because owners were unable to evaluate and develop a stabilization plan in time. Owners or members of the preservation community may engage their own engineers with specialized knowledge to challenge a demolition order.

During times of emergencies, many communities, banks, and insurance agencies will not be in a position to evaluate alternative approaches to dealing with damaged historic buildings. Therefore, they often require full compliance with codes for new construction for the major rehabilitation work required. Because seismic aftershocks may further damage a weakened building, the inability to act quickly—even to shore up or stabilize the structure on a temporary basis—can result in the building's demolition.

Penetrating rain, uneven settlement, vandalism, and continuing aftershocks can easily undermine a building's remaining structural integrity. Moreover, the longer a building is unoccupied or non-income-producing, the sooner it is likely to be torn down in a negotiated settlement with the insurance company. All of these factors work against saving buildings damaged in earthquakes. Thus, having a recovery plan already in place is highly recommended.

Having an established emergency plan, complete with access to plywood, tarpaulins, bracing timbers, and equipment, will allow quick action to save a building following an earthquake. Technical assistance programs are available from the federal government after a natural disaster. Grant funds or low-cost loans from federal, state, and Congressional special appropriations are targeted for qualified properties, which can help offset the cost of rehabilitation (see information about FEMA).

## Summary

Recognizing the seismic vulnerability of historic buildings is an important step toward saving and protecting the built heritage in earthquake-prone areas. Vulnerability resulting from lack of maintenance and improper repairs that weaken the structural integrity of a building must not be overlooked. Even prior mitigation work can become ineffective over time if buildings are not adequately maintained. Unlike many other natural disasters, earthquakes come with no warning and can result in devastating loss of life and property. Therefore, preparedness cannot be overemphasized.

Damage to historic buildings after an earthquake can be as great as the initial damage from the earthquake itself. The ability to act quickly to shore up and stabilize a building and to begin its sensitive rehabilitation is imperative. Communities without earthquake-hazard-reduction plans in place put their historic buildings—as well as the safety and economic well-being of their communities—at risk.

Simple measures such as bracing parapets and chimneys, tying buildings to foundations, and anchoring brick walls to floors and the roof, are extremely effective mitigation measures. However, even simple measures such as these can cause damage to historic materials or impact the visual qualities of a historic building when not properly executed. For this reason, engaging qualified and experienced professionals and workers when undertaking seismic retrofit work is important.

Finally, modern research has helped develop various new seismic retrofit techniques that, added to more traditional methods, provide many approaches to strengthen buildings in earthquake-prone areas. These techniques must be carefully evaluated and chosen so that the process of mitigating potential seismic damage avoids unnecessary removal of historic materials and retains the character of historic properties.

## Glossary

**BASE ISOLATION:** Also referred to as **Seismic Base Isolation** or **Base Isolation System**, is a technique aimed at isolating or separating a building or structure from the movement caused by earthquakes by means of a flexible layer between the foundation and the vertical supports.

**BRACED FRAME:** Essentially, a vertical truss, or its equivalent, added to a building frame to resist lateral forces.

**COLLECTOR:** A member or element provided to transfer lateral forces from a portion of a structure to vertical elements of the lateral force-resisting system (also called a drag strut).

**CORE DRILLING:** A vertical reinforcement system that relies on drilling a continuous vertical core that is filled with steel reinforcing rods and grouting to resist in-plane or out-of-plane bending.

**CRIPPLE WALL:** A short wall between the foundation and the first-floor framing.

**DAMPING:** The internal energy absorption characteristic of a structural system that acts to attenuate induced free vibration.

**DIAGONAL BRACES:** Inclined components designed to carry axial loads, enabling a structural frame to act as a truss to resist lateral forces.

**DIAPHRAGM:** A horizontal, or nearly horizontal, system designed to transmit lateral forces to the vertical elements of the lateral force-resisting system. The term “diaphragm” includes horizontal bracing systems.

**FIBER WRAP REINFORCEMENT:** A synthetic compound of filaments that increase the shear capacity of structural members.

**DUCTILITY:** The ability of a structure or element to dissipate energy inelastically when displaced beyond its elastic limit without a significant loss in load-carrying capacity.

**FAULT RUPTURE:** A break in the ground along the fault line during an earthquake.

**GLOBAL STRENGTH:** The lateral strength of the vertical oriented lateral force-resisting system at the effective global yield point.

**GLOBAL STIFFNESS:** The stiffness of the entire lateral force-resisting system.

**GROUTED BOLTS:** Anchor bolts set in a grout mixture.

**INTERSTORY DRIFT:** The displacement of one floor level relative to the floor level above or below.

**LATERAL FORCE-RESISTING SYSTEM:** The part of the structural system assigned to resist lateral forces.

**LIQUEFACTION:** A condition where the soil underneath or around the building loses cohesive strength and behaves like a liquid during an earthquake.

**LIFE SAFETY:** Providing a level of assurance that risk of loss of life is kept to minimal levels. For buildings, this includes strengthening to reduce 1) structural collapse, 2) falling debris, 3) blocking exits or emergency routes, and 4) prevention of consequential fire.

**MOMENT FRAME:** A structural frame system in which seismic shear forces are resisted by shear and flexure in members and joints of the frame.

**POUNDING:** The action of two adjacent buildings coming into contact with each other during an earthquake as a result of their close proximity and differences in dynamic response characteristics.

**RE-ENTRANT CORNER:** A corner on the exterior of a building that is directed inward such as the inside corner of an L-shaped building, where the two perpendicular portions of the building meet.

**SEISMIC REHABILITATION:** Modifications to existing components, or installation of new components, that correct deficiencies identified in a seismic evaluation to achieve a selected rehabilitation objective.

**SHEAR WALL:** A wall, bearing or nonbearing, designed to resist lateral forces acting in the plane of the wall.

**SHOTCRETE:** Concrete that is pneumatically placed on vertical or near vertical surfaces, typically with a minimal use of forms.

**SOFT STORY:** A story in which the lateral stiffness is less than 70 percent of the stiffness of the story above.

**STRUCTURE:** An assemblage of framing members designed to support gravity loads and resist lateral forces. Structures may be categorized as building structures or non-building structures.

**WEAK STORY:** A story in which the lateral strength is less than 80 percent of that in the story above.

### Federal Emergency Management Agency (FEMA)

In March 2003, FEMA and 22 other federal agencies, programs and offices became part of the Department of Homeland Security. FEMA’s role and mission continues to focus on building, sustaining, and improving the nation’s capacity to prepare for, protect against, respond to, recover from, and mitigate all hazards. FEMA offers a variety of earthquake-related resources including reports, handbooks, guides, manuals, software, web-based tools, and instructional materials. These documents contain nationally-applicable technical criteria intended to ensure that buildings will withstand earthquakes better than before. There is a great deal of information that is applicable to historic buildings, although they are not necessarily identified as a separate category. Most of the information is available online at [www.fema.gov/earthquake](http://www.fema.gov/earthquake). Information on how to obtain hard copies may be found on the web site.

### National Earthquake Hazards Reduction Program (NEHRP)

The National Earthquake Hazards Reduction Program (NEHRP) leads the federal government’s efforts to reduce the fatalities, injuries, and property losses caused by earthquakes. Congress established NEHRP in 1977, directing that four federal agencies coordinate their complementary activities to implement and maintain the program. These agencies are FEMA, the National Institute of Standards and Technology (NIST), the National Science Foundation (NSF) and the U.S. Geological Survey (USGS). More information about NEHRP is available online at [www.nehrp.gov](http://www.nehrp.gov).

## References

Agbabian, M.F. Masri, and R.L. Nigbor. "Evaluation of Seismic Migration Measures for Art Objects." *Getty Conservation Institute Scientific Program Report* (1990).

American Society of Civil Engineers. *Seismic Rehabilitation of Existing Buildings*. ASCE/SEI Standard 41-13 (2014). Reston, VA.

California Historical Building Code, California Code of Regulations. Title 24, Part 8. California Building Standards Commission, 2010.

Federal Emergency Management Agency (FEMA). *A Benefit-Cost Model for the Seismic Rehabilitation of Buildings*. FEMA 227 (1992). Washington, DC.

FEMA. *Engineering Guideline for Incremental Seismic Rehabilitation*. FEMA P-420 (2009). Washington, DC.

FEMA. *Incremental Seismic Rehabilitation of Retail Buildings*. FEMA 399 (2014). Washington, DC.

FEMA. *Incremental Seismic Rehabilitation of School Buildings*. FEMA 395 (2003). Washington, DC.

FEMA. *Seismic Evaluation and Retrofit of Multi-Unit Wood-Frame Buildings With Weak First Stories*. FEMA P-807 (2012). Washington, DC.

FEMA. *Techniques for the Seismic Rehabilitation of Existing Buildings*. FEMA 547 (2007). Washington, DC.

International Code Council (ICC). *International Existing Building Code* (2015). Falls Church, VA.

National Park Service (NPS). *Museum Handbook*, Part I, Museum Collections, Chapter 10, Emergency Planning. <http://www.nps.gov/museum/publications/MHI/CHAP10A-B.pdf>

## Acknowledgements

Antonio Aguilar, Senior Historical Architect, Technical Preservation Services, National Park Service, revised *Preservation Brief 41: The Seismic Retrofit of Historic Buildings: Keeping Preservation in the Forefront*, originally written by David W. Look, AIA, Terry Wong, PE, and Sylvia Rose Augustus and published in 1997. The revised Brief contains expanded and updated information as well as new color photographs describing the general issues and needs associated with the seismic rehabilitation of historic buildings.

The author wishes to thank the following: Melvyn Green, SE, Melvyn Green & Associates, Inc., for his guidance and expertise in the revision of the Brief; Stephen Day, AIA, Stephen Day Architecture, Andrew Phillips, Associate Architect, SMR Architects, and Meredith Wirsching, NCARB, for their input in the initial planning of the revision; Alan Dreyfuss, AIA, Wiss, Janney, Elstner Associates, Inc., Loring A. Wyllie Jr., Senior Principal, Degenkolb Engineers, Timothy Brandt, AIA, Senior Restoration Architect, and Mark C. Huck, AIA, Restoration Architect, from the California Office of Historic Preservation, Nicholas Vann, AIA, State Historical Architect, Washington Department of Archaeology & Historic Preservation, Sueann Brown, Regional Historical Architect, Pacific West Region, and Jason Hagin, Historical Architect, Golden Gate National Recreational Area, National Park Service, for their assistance in reviewing various drafts of the brief; and to Charles Fisher, Brian Goeken, Anne Grimmer, Elizabeth Milnarik, and Gary Sachau, Technical Preservation Services, National Park Service, for their help in the final edits of the publication. Illustrations not specifically credited are from National Park Service files. Front cover image: Damage to a ca. 1910 building in Napa, California caused by the South Napa earthquake in 2014. Photo: Wiss, Janney, Elstner and Associates, Inc.

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. This publication is available from the Technical Preservation Services website at <http://www.nps.gov/tps/> or hard copies may be purchased from the Government Printing Offices at the U.S. Government Bookstore.

Comments about this publication should be addressed to: Technical Preservation Services, National Park Service, 1849 C Street, NW, Washington, DC 20240. This publication is not copyrighted and can be reproduced without penalty. Normal procedures for credit to the authors and the National Park Service are appreciated. The photographs used in this publication may not be used to illustrate other publications without permission of the owners.