PRACTICAL GUIDE

HVAC FOR HISTORIC BUILDINGS

By
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Successfully introducing modern mechanical systems (HVAC) into historic buildings may be the most challenging aspect of an historic rehabilitation program. When that building is also used as part of an interpretive museum, it is generally the most controversial. Mechanical engineers must design for both the building and the collection. Planning changes to the interior environment of an historic building requires professionals knowledgeable in multiple disciplines. Without a team approach and thorough analysis, there is bound to be disappointment in the final product. Architects, engineers, curators, conservators, building owners, manufacturer's representatives, contractors, and others should see and understand the building in its historical context before they recommend changes.

Many existing historic buildings with antiquated or non-existent systems have survived in a state of comfortable equilibrium through daily and seasonal shifts in temperature and relative humidity without undue stress to either the building or the collection. Many of the historic features of the building were designed originally to help manage the climate in the region. Introducing new high-performance systems into this equilibrium generally results in both physical and visual changes. The stewardship role for owners of significant properties requires giving careful consideration to protecting historical materials that might otherwise be removed, damaged or disfigured as part of a new HVAC system.

When considering new systems, environmental conditions required by museum conservators may be difficult to achieve in a preservation context. Guidelines known as the *Secretary of the Interior's Standards for the Treatment of Historic Properties*[1] call for protecting both the historic materials and the historic appearance of the building. Even when systems that will benefit the building and its collection are designed, the HVAC will rarely conform to new building performance standards. In reality, the process of designing new systems for historic buildings is a series of compromises. In some rare cases, it may even be best to avoid installing new systems in landmark buildings if they would result in removal of historic materials or change how visitors experience the property. Some thoughtful stewards, such as the National Trust for Historic Preservation, after years of monitoring existing conditions, have made the decision not to install HVAC at nationally significant properties such as Drayton Hall near Charleston, South Carolina.

This brief article cannot definitively state which HVAC systems are appropriate for historic buildings, because there are a wide range of systems, based on cost and performance, in use throughout the country. Since each historic building has its own performance characteristic, what is described as successful or appropriate for one building may not be appropriate for another. There are, however, guidelines that should be considered when new systems are contemplated for historic buildings. These guidelines are intended to protect both the historic building and, if appropriate, the historic collection. Key points to remember are:

- Historic or low-tech systems can be effectively used/retained.
- Every new dynamic created with systems has some effect on adjacent materials.
- Moisture as a result of new systems is a reality that must be factored into mitigation.
- Historic buildings are made of finite original material; removing any of this fabric removes part of history and is not reversible.
- Building surfaces must contain the interior climate; collections and artifacts are surrounded by it.
- Isolating valuable collections in specialized exhibit cases or separate museum buildings is an option that may need to be considered.
- Building and collections conservators are accepting wider ranges of temperature and relative humidity swings than in the recent past.

Learning from History

With the interest in sustainable design in the late 20th century, there is a new-found appreciation for the natural or passive systems that our ancestors used to make buildings more comfortable. We are often intrigued that the siting of the buildings, or the inclusion of porches, shutters or other sun controlling architectural features, and the judicious use of deciduous trees around buildings were conscious energy decisions by the early designers. Historic buildings remind us that buildings maximized shelter for their owners and made life more comfortable. These developments in the history of architecture and mechanical engineering should not be lost as buildings are rehabilitated for new or continued use.

The builders of the 18th century and those later who designed vernacular buildings incorporated simple elements (no-tech) *to manage the environment*. Since land was generally available, sites were selected to take advantage of prevailing winds, good drainage, sun orientation, seasonal sun angles, and selective landscape features and vegetation. Building plans in cold climates tended to be compact around fireplaces with more wall than windows on the exterior. Buildings in warm, humid climates tended to be open, with cross ventilation, large windows and often a cupola that acted as a venting chimney. Shutters provided protection as well as ventilation, insulation, and sun shading. Buildings in desert conditions had thick masonry adobe walls and few openings in order to contain the coolness of evening temperature for the next day's comfort. Internal courtyards, both for dry and humid climates, provided comfort for daytime use. Choices of materials and construction methods reflected available technology as well as common sense. There was an amazing efficiency in how these buildings stayed as comfortable as possible seasonally (see *Figure 1*).

***Figure 1:** Historic buildings often come with a variety of useful elements that can be reused or can help lower the heating and cooling loads on a new HVAC system. In this California mission, heavy adobe walls, deep tile roof overhangs, covered verandas, the bell tower and the high interior nave, all work to reduce the heat build-up and move air through the building. Architects and engineers should include these passive benefits when calculating energy loads.*

With the industrial revolution of the 19th century, the forms of buildings changed, and mechanized systems were incorporated *to control the environment*. Central heating with steam and hot water radiators, the use of heated air to rise through decorative floor registers, and extensive hot air distribution systems freed building plans from the need to be near a fireplace. Large cupolas and towers, interior atriums, and skylights made interior climates more comfortable, particularly in hot areas. New building systems reflected fireproof technologies and plumbing and venting systems improved living conditions, sanitation and other health-related issues. These features can still be used today, as seen in the Thoreau Center at the Presidio of San Francisco (see *Figure 2*).

The technological advances in the 20th century tended to divorce architecture from its natural environment. Mechanical systems were fully integrated into the architecture *to create interior climates.* In the 1920s, large-scale theaters and auditoriums introduced early air-conditioning systems into buildings, and by post-WWII, buildings were using ducted systems throughout for both heating and air conditioning. Museum collections became more aware of the need to protect fragile objects, textiles, furniture and paintings with more selective control of the immediate environments. The advantages of humidification for protecting collections improved HVAC and became the norm for modern museum buildings. As historic buildings changed use and were converted to museum spaces, particularly during the bicentennial of this country, humidified central systems became the standard. Many of these systems, now needing replacement, are being reevaluated.

With our concern for protecting the global environment and using energy judiciously, and with an understanding that many humidified systems are too aggressive for fragile historic buildings, it is important for mechanical engineers to help find appropriate solutions. Engineers are looking for more moderate systems, more multizoned or multiunit systems, more sophisticated warning systems, better safety or back-up capabilities so systems do not completely shut down, and a tailoring of the system to the multiple needs of the client. The system must work with the building and be appropriate to the needs, finances, and maintenance abilities of the owner or institution. New design criteria cannot just be an idealized standard extracted from a mechanical equipment manual. That unsuccessful system may be akin to, and just as impractical, as placing a jet engine in a paper bag.

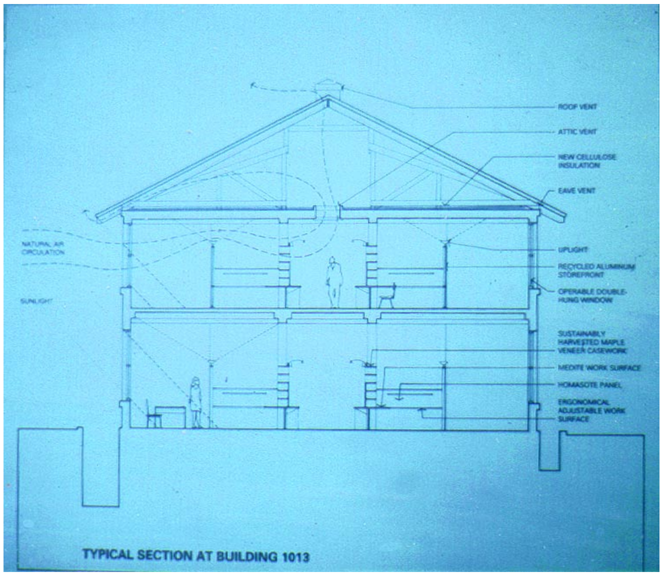

Figure 2: Utilizing natural or passive systems can work well in mild climate, and reusing older systems can be cost-effective. In San Francisco, the new Thoreau Center for Sustainability, located in a renovated wooden military hospital, uses operable windows for cooling and cross ventilation, attic vents and roof monitors for drawing air through, and upgraded boilers for the historic radiator system. Almost all of the construction and finish materials are from recycled or sustainable materials. The only air conditioning is relegated to the center core of the building to provide a controlled climate for the new computer systems.

Figure 3: The Shelburne Museum, an outdoor art and history museum in Vermont, uses well-disguised ventilation fans with dust filters. The fans are controlled by humidistats to cool and lower humidity in buildings during warm weather. Increased air motion helps control mold growth. During the winter when the museum is closed, temperatures are lowered substantially to increase beneficial relative humidity. Humidistatically controlled heating is used to reduce humidity in buildings during cool wet spring and fall weather.

Critical HVAC System Issues

Installing HVAC systems in historic buildings is almost always expensive, and poor decision-making is not readily correctable. There are three critical issues:

1. The impact of the HVAC on the interpretation of the site.
2. The inherent conflict between the climate needs of the collection versus the building.
3. The challenge of installing the system in as sensitive a manner possible, which generally means hidden from sight.

Owners of historic buildings and the design team planning new systems are responsible to step back and evaluate the existing building so the performance objectives for the new system can be met without damage to either the building or, if applicable, its collections.

Impact on Interpretation

The interpretive issue is one that must be decided by the owner with input from the museum staff. For buildings that are part of an exhibit, for example, a period house museum, owners must ask if the use and visual appearance of modern mechanical systems are appropriate. If it is inappropriate for visitors to enter an air-conditioned space while docents are describing the difficult living conditions of pioneer families, it might be best to rely on natural, passive systems or ventilation with a minimal amount of modern HVAC to more accurately reflect history. The mechanical engineer familiar with low-tech systems or the benefits of enhanced filtered ventilation, or the reuse of improved historic equipment can help with the design of these more moderate system. Shelburne Museum in Vermont has consciously used a variety of these low-tech systems to give the visitor a more accurate feeling for history while at the same time providing added protection to their collections (see *Figure 3*).

Conflict Between Collections and Buildings

The inherent conflict between the conditions necessary to preserve a building and the curatorial needs of collections based on their materials, age, and condition has been at the center of controversy within the museum and preservation community for some time. There is no definable ideal temperature and relative humidity for all historic buildings. Anyone who suggests that an historic building with a period collection of objects should include a forced air humidified system set at 70°F (21°C) and 50% relative humidity with a 2°F (1°C) and 2% drift in RH has probably not undertaken the full evaluation necessary to determine what is best for each component of the museum. This curatorial standard, formerly thought to be ideal, is rarely attainable in existing historic buildings. It creates enormous energy costs and has proven to cause condensation damage to some historic buildings. Unfortunately, many insurance companies still hold to these standards when writing policies for artworks on traveling exhibition or on loan. This has perpetuated the application of this rigid standard to many collections found in historic buildings.

Building conservators and curators are now willing to accept wider temperature and relative humidity fluctuations. The key is to control the drift of relative humidity and allow temperature to fluctuate in a wider span. While each situation must be assessed, temperatures ranging from 45°F (7°C) in winter to 80°F (27°C) in summer with relative humidity from 30% in winter to 75% in summer are possible. Seasonal shifts and drifts must be controlled to avoid sharp peaks or drops (see *Figure 4*).

Most collections can work within these parameters or be placed in climate controlled cases or storage. Buildings generally do well within these parameters, but buildings prone to rising damp may show damage below about 50°F (10°C). Dimensional changes in building materials, particularly assemblies made up of different materials, can occur above 80°F (27°C) or if the building is allowed to freeze.

Paintings, wood paneling, inlaid furniture, and small decorative objects of ivory or other fragile materials can be severely affected in winter if the humidity levels drop too low and the heating is too high. Likewise, mold and mildew may appear on fabrics, leather, and wooden surfaces if the humidity gets too high, so monitoring and controls are necessary in many situations. Dew point cannot be ignored because condensation is a major concern. Fan ventilation systems controlled by humidistats can provide low-tech mitigation for buildings that experience high temperatures and high relative humidity.

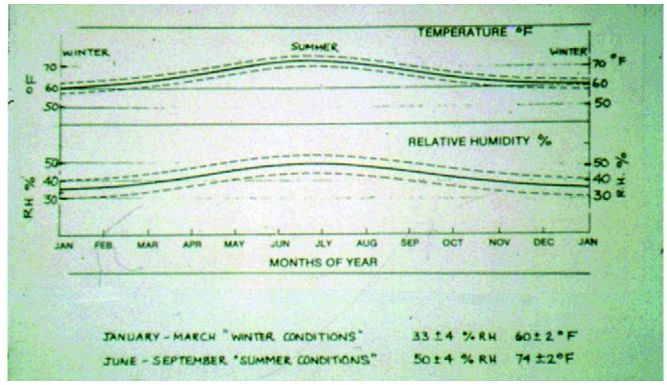

***Figure 4:** This chart shows the range of temperature and humidity incrementally programmed for the Frank Lloyd Wright Home and Studio, Oak Park, Illinois. In the Studio, a slow drift from winter conditions at 60°F (16°C) in January to 74°F (23°C) in July is carefully tracked by 33% RH in January to 50% RH in July. Visitors to the studio are generally wearing coats in winter, and the docents are in the building only while guiding tours. This wider range of temperature is a trend that more museums are considering when seeking a balance for both the collections and the buildings.*

Hiding Systems from Sight And Minimizing Impact on the Building

Determining how a new system can be installed with minimal impact to the building requires teamwork with an experienced preservation architect. There is a stewardship responsibility in historic buildings to protect original materials. Designing a compatible system will depend on how much original fabric remains in the building, how much of past alterations can be used to advantage, and how the building is laid out. Gutting interiors or reconfiguring them to hide large chases and duct runs can do extreme harm to historic materials.

The mechanical engineer is, therefore, challenged to design a system with the other team members that utilizes existing historic cavities, mezzanine balconies, stair landings, stair skirt panels, unused chimneys, small closets, and other secondary spaces or cavities provided by the building itself. Old floor or ceiling hot air grilles can be reused as supply or return registers that retain the historic character of the building. New slot registers can be used at baseboards or cornices, and wall grilles can be custom designed or painted to take on the pattern or color of the background walls, moldings, paneling, or floor surfaces.

Existing skylights that penetrate attic areas can form a natural supply or return to the plenum. Some house museums have even retained radiators and decorative radiator covers as evidence of former systems even when they have been replaced with forced air or fan coil systems.

Engineers should look to the building itself for clues to help reduce energy loads or to hide equipment. Beginning at the bottom, assess available basement or crawl space for types of systems currently in place and distribution available for reuse (duct space). Also look for chases, dumbwaiter shafts, coal chutes, chimneys, or other cavities that can be incorporated into mechanical space.

On the floors above, look for areas to hide equipment or grillwork. In some buildings, earlier alterations have covered over fireplaces, stove flues, pipe organ chambers, or hidden vaults. Often large built-in cabinets, buffets, closets or window seats can provide places to tuck equipment. Taking advantage of porch overhangs can screen out summer sun while allowing lower angled winter sun to warm a front room. The use of room darkening shades or interior shutters can become part of the daily housekeeping routine of the staff to control solar gain and to reduce ultraviolet light damage to interior collections.

Moving up through the building, there may be tall stair towers, cupolas or atria indicating that wall chases with hidden venting systems are present. Attics, roof monitors, and dormers can provide areas for air intake, ventilation fans, and air handlers. Working with the historical architect, secondary spaces should be identified that could be for mechanical use without interfering with the interpretation or appearance of the property.

Compatibility also relates to the location of controls, monitors, security alarms, smoke detectors, thermostats, etc., if they would be distracting to the interpretation of the spaces. Depending on how the spaces are viewed by the visitors, there may be more desirable locations immediately overhead or behind portions of the exhibit. Curators and facility managers can help select locations for these important components. Likewise, louvered vents, fan housings, air handlers, chillers, and other visible equipment should be appropriately screened from view. In most cases, blending the HVAC and all its component parts into the historic building and its surrounding site requires custom work and a sensitivity of the entire design team to the historic appearance of the space before any modifications. Utilitarian and industrial spaces, for example garages or stables converted to exhibit space, may be able to accept a more visible and functional system. In that case, the exposed ductwork, associated hardware and modern grilles may be appropriate.

Creativity should not be discouraged when new systems must be integrated into historic spaces. In the case of monumental spaces, sometimes the best approach is to use vertical elements, such as free standing supply pylons seen at Union Station in Washington, D.C., or to locate supply registers above designed elements or cabinetry within a space. With fine elements of craftsmanship present in historic buildings, custom details should be expected as part of the new work as well (see *Figure 5)*.

Figure 5: It is often possible to reuse existing grilles as supply or return registers. In the Mills Museum in New York State, a modern climate control system reused existing duct runs and the historic grilles, as seen here.

With architects, engineers, and others on the team working to find a compatible solution, a wide range of solutions will generate more thought than the traditional boxed corner, dropped soffit, and large rectangular registers that so often disfigure elegant historic interiors.

Functional Considerations

For historic buildings, it is important to establish realistic goals, such as simplicity, efficiency, manageability, and appropriateness, for the new HVAC system. A systematic approach that evaluates the ability to adapt the building without destroying its historic character and includes follow-up monitoring can reduce the risk of future damage. The ability to use natural or passive systems should not be overlooked as part of analyzing changes to the interior climate. Engineers should also look for ways to reduce building energy needs through more effective systems, reducing heat gain from lights and equipment, use of shutters, shades, thermal storm panels, setback thermostats, and other energy-saving features. Even administrative decisions to zone certain areas that have greater humidification requirements to interior spaces of a building or to set zones to control off-season drops in use can result in smaller or more efficient systems.

System Selection

Many types of systems can be made to work in a historic building, though no system is perfect or free of future problems. The choice of system will depend on cost, compatibility, controls, and comfort. Most modern systems are replaced approximately every 25 years, so whatever system is installed should, to the extent possible, cause as little damage as possible to structural systems and historic finishes and should be removable when obsolete. Improved reheat systems which can efficiently capture and re-use thrown-off heat are being used more frequently. As with any museum system, data loggers, hygrothermographs, and other monitors should be considered to track dew points and to check that condensation, mold growth, or other damage are not occurring. These museum systems are generally controlled by computers, and as such, require a high degree of staff training and maintenance contracts.

Some owners choose to pair existing hot water systems with separate new air conditioning. Forced air systems are popular as they have a greater variety of performance features and can integrate humidification, but long duct runs can do extensive physical and visual damage during installation. Using multiple smaller units or zoned controls can work well with more formal spaces because they can be located in closets, behind stairs, or other secondary spaces.

Piped water systems have their place in historic buildings because small piping can eliminate a lot of cutting and bulky soffits often required with large ductwork. Water systems can be fan coils or heat pumps. Cabinet fan coils generally have no humidification so are better suited to office or support spaces or for geographic climates where humidity ranges are not a concern. However, many museums use multiple fan coil systems tucked into closets and small areas between rooms with short duct runs fitted with humidifiers. This approach has been successful at the Frank Lloyd Wright Home and Studio in Oak Park, Illinois, which maintains an environment unencumbered by any appearance of modern mechanical systems (see *Figure 6*).

These water systems, however, generally require routine maintenance to clean condensate pans and do pose a threat if leaks occur. Piped water systems, as with any plumbing system, should not have piping runs directly over exhibit or collections storage areas.

Fan coil systems may use a central water chiller or a series of small split systems with an equal number of exterior condensing units. Grilles and registers can be custom designed or historic elements can be reused. Equipment is often located in attics and basements and multiple systems can reduce the amount of visible ductwork or chases between floors. Fireplace chimneys and stacked closets can be used for vertical duct runs, as seen in a variety of Colonial homes that had massive, centrally located chimneys (see *Figure 7*).

Ground vaults are being used more extensively because they remove large air handlers and other equipment from the

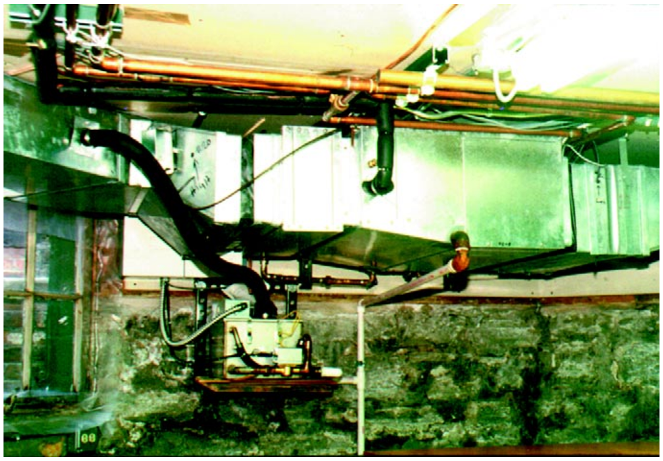

Figure 6: Piped water to fan coil systems can also be installed in a compatible way. At the Frank Lloyd Wright Home and Studio in Oak Park, Illinois, individual fan coils with humidification are located in the basement and have short ducted runs to numerous cabinets and other built-in furniture on the first floor. Supply is either through grilles at cabinet counters or through toe hole slots. In the upstairs vaulted ceilings, recessed slot registers were concealed between trim strips that outline plaster sections.

Figure 7: Ducted central HVAC systems have been used in a compatible way at Gunston Hall in Virginia, the 18th century home of George Mason. As seen in this view, there are no dropped bulkheads, soffits, or ceiling registers to disfigure the elegance of this historic room. The chimney serves as a supply. This house museum has a stable furnishing collection, and the HVAC is not fitted with humidification. In winter, the relative humidity occasionally drops below 25%, but monitoring does not reveal that the collection is being damaged. The house stays heated in winter because the docents are in the house during the day. Special fragile collections are exhibited in the climate-controlled visitors center.

house, can serve several buildings, can reduce vibration, are easier to service, and make equipment replacement easier in the future. The American Architechtural Foundation, an af-filiate of the American Institute of Architects, in its own recent restoration of the 18th century Octagon House in Washington, D.C., removed extensive equipment from the attic and basement and placed it in a new ground vault. This also freed the basement to be interpreted as the service quarters as part of the history of the property.

Operating costs can affect system choice. It has been estimated (in a simplified, abstract fashion) in the mid-Atlantic region that HVAC can cost \$0.50/ft^2/yr (\$0.05/m^2/yr) for general heating and fan ventilation to \$1.00/ ft^2 (\$0.10/m^2) for central heating and cooling to \$2.00/ ft^2 (\$0.20/m^2) for HVAC with humidification to over \$4.00/ ft^2 (\$0.40/m^2) for high-tech monitored multiple zone museum systems. Owners should be well apprised of the cost of maintaining and operating a system as well as the initial cost of the capital improvement.

Computer-controlled systems may require a trained facilities staff person half time and an expensive annual contract for the computer portion alone. If it is determined that a sophisticated climate controlled system is appropriate for the property, then it is important to train several staff on how to monitor and maintain the system as part of the installation contract.

Making HVAC Compatible

Compatibility is important on two fronts. The first is the visual appearance, as discussed earlier. The other is that the building envelope must be able to handle the system as designed. This means that the system must be adjusted, for the most part, to the building, and the controls must work within the tolerance of both the building and the collection.

Respecting the Building Structure

Significant historic buildings should not be altered to improve thermal performance beyond the point where the historic character or the loss of materials will be too great. This is particularly important on the exterior walls of the building. For example, many non-historic masonry building renovations include coating with insulation and a stucco finish to improve thermal performance. This treatment is not appropriate for an historic brick building as it would change the exterior appearance.

Likewise, removing the historic interior plaster or exterior wooden siding on a frame building to add insulation and a vapor retarder is rarely appropriate for an historic building. Energy improvements should center on improving insulation in attics and crawl spaces, adding well-designed storm windows, if necessary, and caulking or repointing masonry to reduce air infiltration. Reducing unwanted ground moisture through proper gutters and downspouts is also important, because wet basement walls will interfere with the performance of the HVAC.

Because the building envelope must ultimately contain the interior climate generated by the mechanical system, the design team must evaluate many sets of variables. These factors include assessing wall assemblies, the thermal and vapor resistance/transmission of materials and collections, the expected visitation and usage of the buildings, the climate in the region, and the desired interior climate. Since most museum systems have some positive sources of humidification, the need to monitor and control this humidity will be a major part the system design. The greatest risk is too much humidification. System failures often occur at the valves that control how much moisture is released. Masonry structures can hold or buffer wider differentials between interior and exterior conditions and can contain higher vapor pressures better than frame buildings. Insulated frame buildings, unfortunately, can provide a variety of inter-cavity surfaces where condensation can form if there are inadequate or damaged vapor retarders and high humidity inside.

One of the first indications that condensation may be occurring in unseen areas is the presence of condensation on cold surfaces, such as window glass. Another sign is bubbling plaster around register grilles that might indicate condensation on uninsulated sheet metal ductwork from an existing HVAC installation. In buildings with open atria or other stack effect movement of higher vapor pressure/moisture laden air, condensation can occur on upper floor with no evidence on the first floor. When condensation is present, it likely occurs in more than one place.

Strategies should be considered for historic buildings that take the pressure off fragile exterior walls. For frame buildings, one way to reduce the impact of vapor pressure on external walls is to design a system that has more humidification on the interior of the building used for exhibits with a conditioned but not humidified buffer zone toward the exterior. Staff and visitor services can use the buffer zone. In some cases, such as the Frederick Law Olmsted National Historical Site outside Boston, which houses the collection of the premier American landscape architect, there are two distinct environmental conditions. Archives for important records and his collection of plans are kept in a specially designed climate controlled vault. The rest of the exhibit spaces utilize radiator heating for winter and fan cooling for summer, as typical of Olmsted's time.

Another strategy is to use climate controlled exhibit cases, some using desiccants and some positive controlled air, when humidified central systems are not possible but delicate objects, books, articles of clothing or other features need protection. Some museum complexes use a modern visitor center and exhibit area with full climate control capabilities while leaving the historic buildings in a more passive state.

Conclusion

Mechanical engineers and the design team must understand the historic building and use critical thinking and strategies to develop custom HVAC systems for historic buildings. Depending on the owner's program requirements, buildings can be heated, cooled, humidified, dehumidified, or ventilated using a broad range of equipment that can be successfully integrated to preserve the historic character of the space. The building can provide its own positive elements intended to manage the climate, such as porch overhangs, large windows, awnings, skylights, and open stair halls which can be incorporated into a new system. The new system, designed to control the environment, can use an evenly distributed network reusing existing grilles, registers, duct chases, and venting systems. Historic buildings, which also serve as museums, however, provide the design team with added complexities. Solving the humidity question as part of creating a new environment is one of the most challenging tasks. The proposed new system must work with the collection without doing long-term damage to the historic building. In historic projects, preliminary planning and design analysis should not be shortchanged to jump to a quick solution. It is not unusual for diagnostic and monitoring of existing conditions to take a full year to give the mechanical engineer enough building performance data to develop the new HVAC design. Once installed, HVAC systems generally remain for years, so there is a need to understand the building and its eccentricities thoroughly before selecting a new or upgraded system.

Because designing HVAC for historic museums involves compromises, the design team should have realistic performance goals. History has shown that many buildings have been damaged in order to create a new environment for the collections. We now know that many collections can withstand wider temperature and humidity ranges than previously believed. This knowledge is beneficial to finding a balance that also works with protecting historic buildings.

A good starting point with any new system is to evaluate existing conditions and if possible, utilize features in the historic building as part of the new system. It is important for the design team to remember that this system will be in place for decades, and no system can be considered successful if it is too complicated to manage or too expensive for the owner to maintain. We can learn a great deal from history and we can avoid some of the mistakes of the more recent past.

Notes

1. Standards for Rehabilitation, the most commonly applied treatment standard, call for protecting historic materials while modifications are made to bring the building into modern compliance. For the installation of mechanical systems, care must be taken in not demolishing significant interior materials, finishes or spaces. New elements of the mechanical system, such as bulkheads, registers, chases, and the placement of mechanical equipment, should not alter the historic character of the buildings.

Additional Resources

Conrad, Ernest A., P.E. "The dews and don'ts of insulating." *The Old House Journal*, May/June 1996.

Forum; The Journal of the National Trust for Historic Preservation.12(4). Washington, D.C., 1998. This issue includes several articles on installing HVAC in historic buildings and discusses the philosophical issues.

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Moisture Control in Buildings. Heinz R. Trechsel, Editor. Philadelphia: American Society for Testing Materials (ASTM manual series: MNL 18), 1993. [See chapters by William Rose and Sharon Park].

Park, Sharon C. *Preservation Briefs 24: Heating, Ventilating, and Cooling Historic Buildings: Problems and Recommended Approaches*. Washington, D.C.: Department of the Interior, Government Printing Office, 1991.

Park, Sharon C. *Preservation Briefs 39: Holding the Line: Controlling Unwanted Moisture in Historic Buildings*. Washington, D.C.: Department of the Interior, Government Printing Office, 1996.

Web Sites

www2.cr.nps.gov. This web site contains the technical publications of the cultural resource programs of Heritage Preservation Services of the National Park Service and the Secretary of the Interior's Standards for Rehabilitation referenced in Footnote 1. *The Preservation Briefs*, listed earlier, can be found in an abbreviated version on this web site. Ordering information from the Government Printing Office is also available on the web site.

www.cr.nps.gov. This is the cultural resources web site for the National Park Service and contains information on museum management which might be of interest to mechanical engineers.

For an excellent Conservation on Line bibliography by Richard Kerschner on environmental controls go to http:\\palimpsest.stanford.edu\byauth\kerschner\ccbiblio.html.

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