HVAC Retrofit
fitting the pieces together

Preserving Legacy Buildings

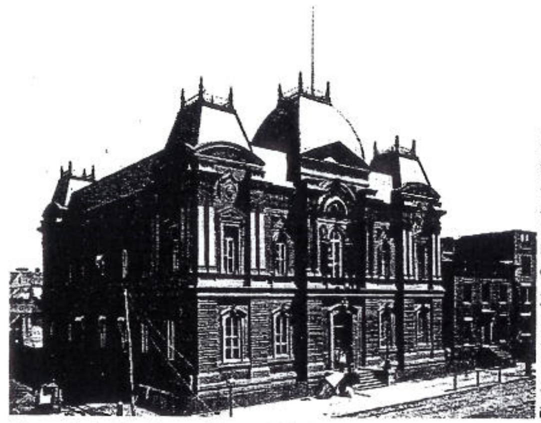


Photo courtesy of the Smithsonian Institution

Renwick Gallery circa 1860.

By Marion F. Mecklenburg, Ph.D.; Charles S. Tumosa, Ph.D.; and Alan Pride

Although preserving museum collections is vital, it is equally important to consider the failure mechanisms of the build- ings that house those collections. A combination of research, survey, and experience with high-profile buildings at the Smithsonian Institution has led to broadening the indoor environmental guidelines. The new environmental guidelines are 45% RH ±8% RH and 70°F (21°C) ±4°F (2°C).

The Smithsonian Institution maintains 16 museum complexes with 434 buildings that total more than 8 million ft^2 (740 000 m^2). Included in the complexes are 62 major chiller plants, 178 major air handlers, 21 steam stations (not counting the steam purchased from the U.S. General Services Administration), and 20 emergency generators that maintain environmental control of the museums. A building automation system with 40,000 points monitors all systems.

Most people know that the Smithsonian Institution houses some of the nation's most prized possessions. Fewer realize that some of the major museum buildings have their own historical value. These mid- to late-19th century buildings were built for other purposes and then retrofitted as museums or galleries.

Buildings for exhibitions and public spaces vary from 135,000 to 1,500,000 ft^2 (12 500 to 140 000 m^2). Renovating these monumental buildings involves the same principles and concepts as renovating smaller buildings, which includes wall insulation, vapor barriers, and special window treatments.[1] Historic buildings, however, incorporate elaborate interior design components are sometimes an integral part of true masonry walls. Insulating those walls is difficult. Unfortunately without wall insulation, high indoor humidity in the winter can cause moisture condensation problems. In other cases, ornate ceilings cannot be covered or lowered to provide space for air-conditioning ducts. Consequently, renovating and retrofitting large, historic buildings sometimes requires rethinking the interior design criteria.

An Integrated Approach

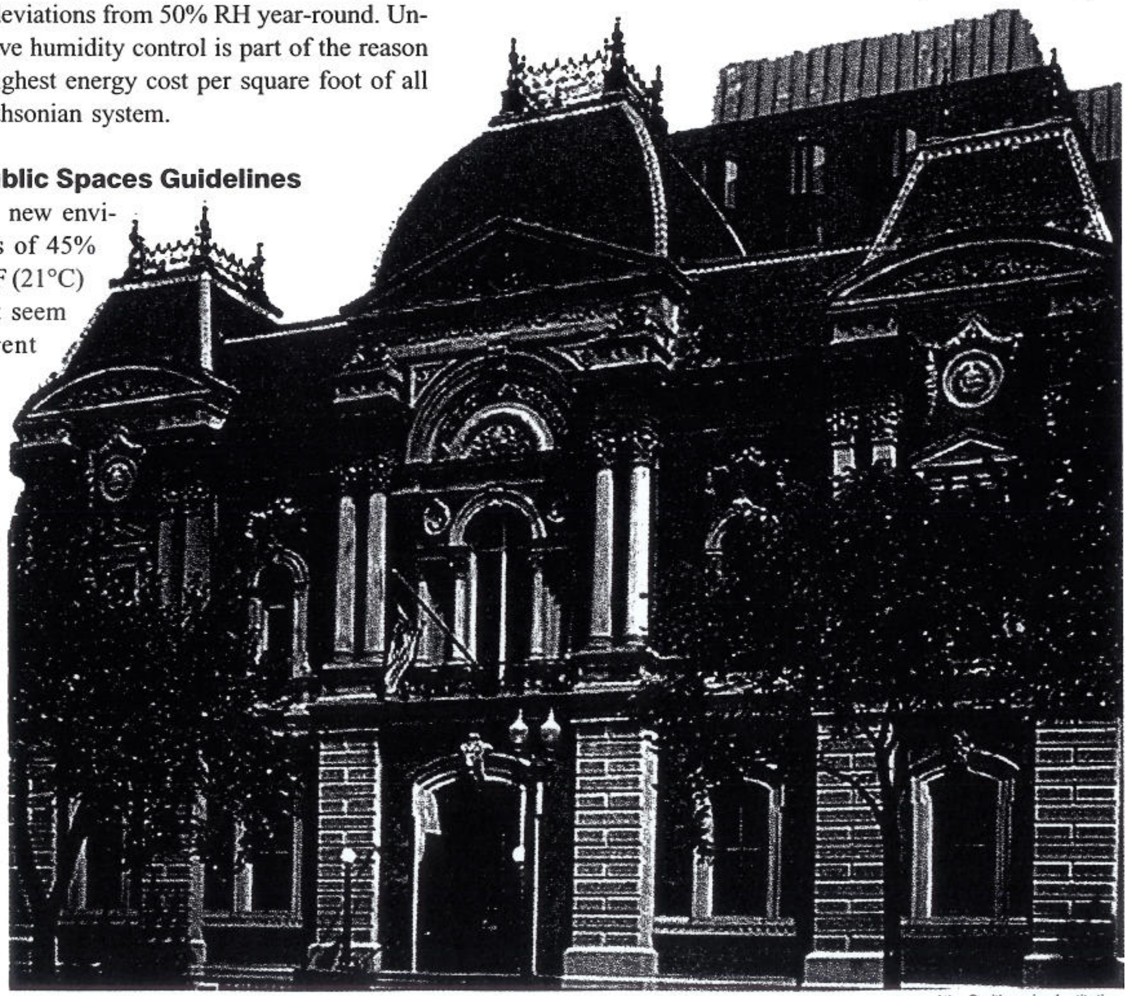
Determining specific temperature and relative humidity setpoints and allowable fluctuations has caused rigorous, if not contentious, debate. At the Smithsonian, guidelines for new buildings often were established at the time the buildings were designed. Guidelines for older retrofitted buildings were established largely by a consensus of recommendations from the museum registrars and the conservation staff. Recommendations voiced by registrars largely reflected the need to accommodate loan requirements from other institutions rather than technical considerations.

Over time, environmental guidelines tightened. If a recommendation of 50% RH ±10% RH was satisfactory for a building initially, it later became 50% RH ±5% RH. As time went on, even tighter environmental controls were recommended. Hydrothermographic readings from the Renwick Gallery show almost undetectable deviations from 50% RH year-round. Undoubtedly, tight relative humidity control is part of the reason the gallery has the highest energy cost per square foot of all buildings in the Smithsonian system.

Exhibition and Public Spaces Guidelines

The Smithsonian's new environmental guidelines of 45% RH ±8% RH and 70°F (21°C) ±4°F (2°C) may not seem significantly different from other recommendations. However, the differences are crucial. First, the relative humidity setpoint has been lowered 5% RH from the traditional 50% RH. Second, these recommendations allow, without restriction, any point within the environmental box formed between 37% RH and 53% RH and from 66°F (19°C) to 74°F (23°C) for the vast majority of the collections. Exceptions exist.

No single environment can be recommended for the extensive mineral collections of the Smithsonian. Other objects are extremely fragile, and any environmental fluctuation might be problematic. These objects are handled on a case-by-case basis using special microclimate exhibition cases. Microclimate cases are cost-effective ways to isolate spe-



A recently discovered problem at the Renwick Gallery caused condensation behind the backs of paintings (see photo, Page S20).

Photo courtesy of the Smithsonian Institution

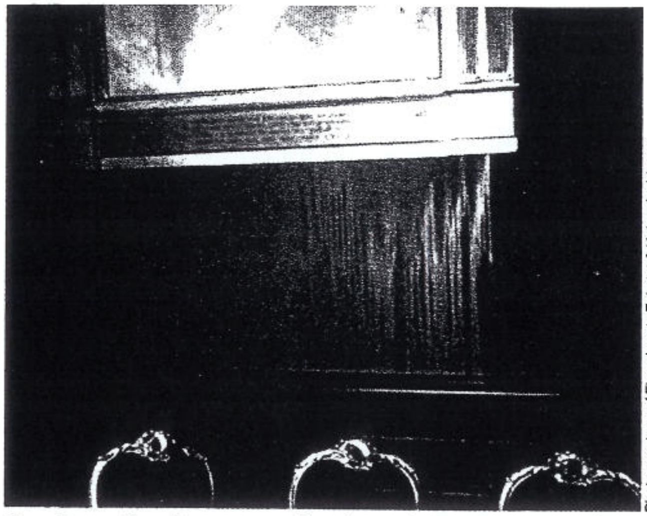


Photo courtesy of Ehrenkrantz Eckstut & Kuhn, Architects

Condensed moisture running down from behind a painting hanging on the interior of the north wall of the Grand Salon of the Renwick Gallery. The surface of the wall behind the painting reached the dew point of the interior environment of 70°F and 50% RH.

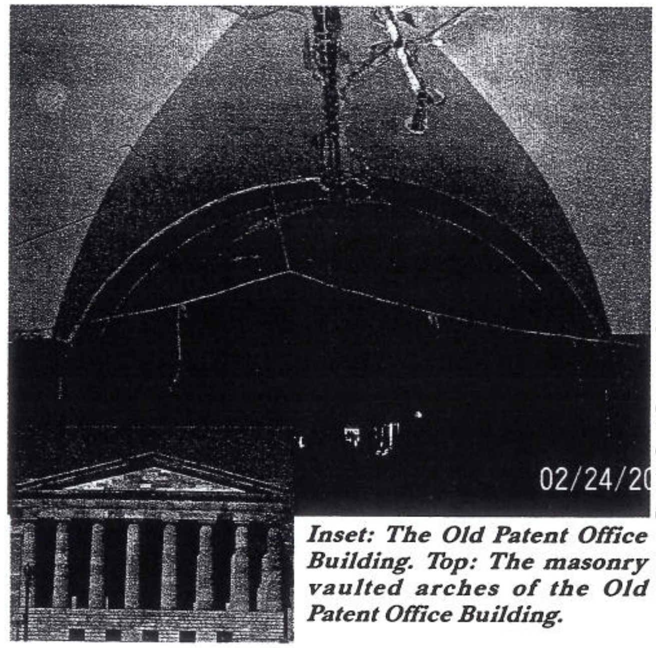


Photo by Sarah Drumming, Smithsonian Institution

Inset: The Old Patent Office Building. Top: The masonry vaulted arches of the Old Patent Office Building.

cific items rather than tightly controlling the entire exhibition or storage spaces.

Years of research into the biological, chemical, and mechanical degradation mechanisms of materials and objects in the collections[2–6] influenced the decision to adopt the new guidelines. In general, materials such as wood, ivory, hide glues, and some paints traditionally considered exceptionally responsive to changes in moisture content are actually considerably less active if maximum relative humidity is kept to less than 70% RH.

Another factor was the need to establish performance benchmarks for the building HVAC systems. Monitoring, trending, and analyzing HVAC system performance can be used to develop maintenance programs to anticipate failures and identify design, as well as operating and maintenance deficiencies. The amount of time when temperature and relative humidity are within the desired band is tracked and trended periodically. Out of service sensors can be identified.

Energy cost also is important. Occupancy codes require a considerable amount of outside air for all of the buildings. On a typical winter day (35°F [2°C] DB and 33°F [1°C] WB; 0.0035 lb/lb [3.5 g/kg] outdoors), conditioning ventilation air to 68°F (20°C)/37% RH (0.0056 lb/lb [5.6 g/kg]) instead of 70°F (21°C)/50% RH (0.0078 lb/lb [7.8 g/kg]) halves the humidification load for ventilation air.

Finally, a comprehensive survey was conducted of environments maintained by other major cultural centers in Europe and North America.[7] An interesting finding was that not all major museums adopted and maintained environments of 50% RH ±5% RH and 70°F (21°C) ±2°F (1°C). Many museums in cold climates successfully maintained environments with much broader environmental allowances.

For example, the Canadian museum system probably has the longest tradition of an integrated environment plan that encompasses the needs of both the collections and the buildings. Early on, the Canadians recognized the adverse effects that high interior moisture levels can have on buildings during harsh winters. Some allow the RH levels to drop to 33% RH on an intermittent basis. (The actual environmental guidelines for most collections from the National Gallery of Canada allow temperatures to range from 65°F to 72°F (18°C to 22°C) and the relative humidity to range with a sliding setpoint of 43% to 50% RH and a fluctuation of ±10% RH in a 24-hour period.)[8]

One of the most important benefits of relaxing interior environmental requirements of historic buildings is the resulting flexibility in system design and installation during building renovation and HVAC retrofit.

The Renwick Gallery

The Smithsonian's Renwick Gallery primarily contains decorative arts such as contemporary crafts, furniture, glass, and ceramics. Built in 1859 by William Wilson Corcoran to house the Corcoran Gallery of Art, it is an excellent example of Second Empire style architecture. It was the first building in Washington, D.C., designed specifically to exhibit art. The architect, James Renwick Jr., also designed the Smithsonian Castle. After serving as the U.S. Court of Claims for nearly 50 years, the building was turned over to the Smithsonian in the mid-1960s.

Between 1967 and 1971, successive and extensive interior and exterior restorations included an HVAC system to control the interior environment at 50% RH with little allowable de-

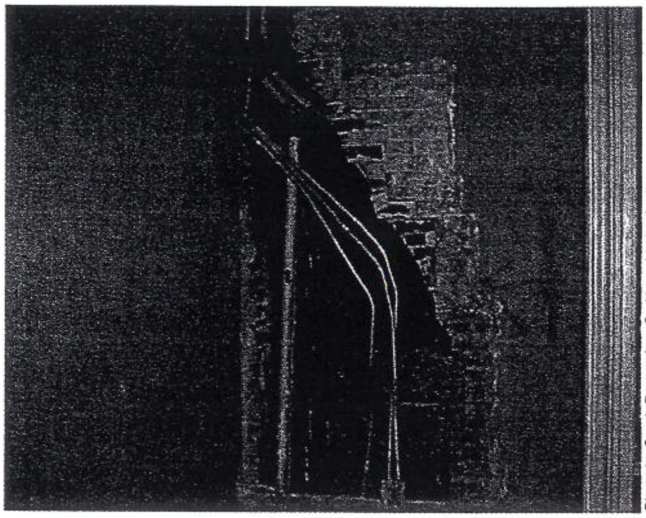


Photo by Sarah Drumming, Smithsonian Institution

Finding space for ducts and pipes without disturbing the architectural details of the interior spaces is a real engineering challenge. An old chimney flue in the Old Patent Office Building used as a conduit chase.

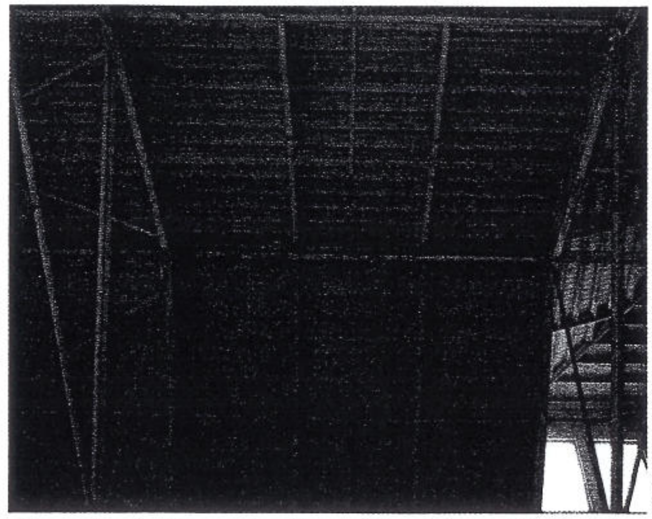


Photo by Kevin Guiffreda and Gary Johannsen, Smithsonian Institution

Corrosion in the roof system of the Arts and Industries Building. High humidity and fire proofing salts in wood spacers of the roofing insulation were largely responsible for this corrosion.

viation. The Renwick Gallery was opened to the public in 1972 as the decorative arts gallery. The Grand Salon, with 4,300 ft^2 (400 m^2) of floor space and 40 ft (12 m) ceilings truly conveys the concept of the traditional picture gallery.

This 34,600 ft^2 (3200 m^2) building is constructed mainly of brick with walls as thick as 26 in. (66 cm) and an additional 16 in. (40 cm) of decorative concrete facing on some portions of the building. Additional insulation and vapor barriers for the exterior walls were considered either unnecessary or impractical. Eliminating the insulation was not unreasonable. Such massive walls have some insulating value, and winters in Washington generally are not excessively cold. However, Washington can have bitter cold spells that last a week or more. When this occurs, the interior surfaces of the exterior walls become quite cold.

Cold walls alone did not cause difficulties. However, paintings hanging on the walls provided enough insulation for the interior wall surfaces to fall below the indoor dew point (approximately 50°F [10°C]) of the humidified building. The combination of the cold wall surface, paintings insulating the wall, and humidification to 50% RH caused significant amounts of condensation behind many paintings in the Grand Salon. This condensation occurred near or just below the interior surface of the walls. The condition is illustrated in *Figure 1*, which shows water from behind a painting. Condensation occurred on the east, west, and north walls of the Grand Salon, which were in full or partial shade for most of the day.[9] This occurred twice during two winters. The condensation was deep enough to dissolve some of the plaster surface materials.[11]

The cost of repairing these massive walls is significant and could have been avoided if the interior relative humidity had been lowered to 40% RH (44°F [7°C]) dew point). Looking back, this seems like a reasonable accommodation, but in 1998 serious objections still existed to any change in the relative humidity from 50%. Thus, the condensation on the walls reoccurred in the winter of 2003–04.

The Renwick Gallery has a tightly controlled interior environment. The Smithsonian inadvertently conducted a 30-year experiment on the stability of paintings in close proximity to the widely fluctuating environment of the stagnant air pockets between the paintings and the wall. The backs of the paintings were exposed to an environment of approximately 100% RH as shown in *Figure 1*.

Summers in Washington have many days when the outside temperature reaches 95°F (35°C). The inside surface of the wall behind the paintings can easily heat up to 82°F (28°C). With the interior environment controlled tightly to 70°F (21°C)/50% RH (50°F [10°C] dew point), the relative humidity of the stagnant air behind the paintings drops to approximately 35% RH.

Until the condensation incidents, the environmental conditions behind the paintings went undetected. Once becoming aware of the situation, it is easy to see that the backs of paintings were exposed to annual RH swings between 35% RH and 95% RH for more than 30 years. However, no damage was reported to any painting. Probably, this is because each painting has a backing board that likely buffered the effect of the RH swings between the wall and the paintings. Nevertheless, the paintings experienced wide RH variations even while the building interior spaces were controlled to 50% RH. This is probably true for the vast majority of paintings mounted on walls in museums and galleries.

Avoiding condensation and keeping the paintings in a more stable environment is a two-step process. These steps include lowering the indoor relative humidity in the winter and letting air circulate behind the paintings. Hanging paintings so there is a clear space of at least 1 in. (2 cm) behind smaller paintings and up to 2 in. (5 cm) of space behind larger paintings avoids stagnant air pockets. With adequate space for air circulation, neither the paintings nor the walls experience large relative humidity swings.

The Old Patent Office Building

The Old Patent Office Building was originally designed by several different architects during a 20-year period. Because of this, the two wings of the building are remarkably different in design and appearance. The building was seriously damaged by a fire in 1877. It was rebuilt in the 1880s.

The building has approximately 330,000 ft² (30 600 m²) of floor area, not counting a new auditorium being constructed below ground in the central courtyard. It is a true masonry building with vaulted arch construction on all of the lower levels. During reconstruction after the fire, large areas of mezzanines were added to the building. These upper levels were constructed of 1.5 in. (4 cm) thick slate tiles supported by 12 in. (30 cm) deep wrought iron I beams on 5 ft (1.5 m) centers.

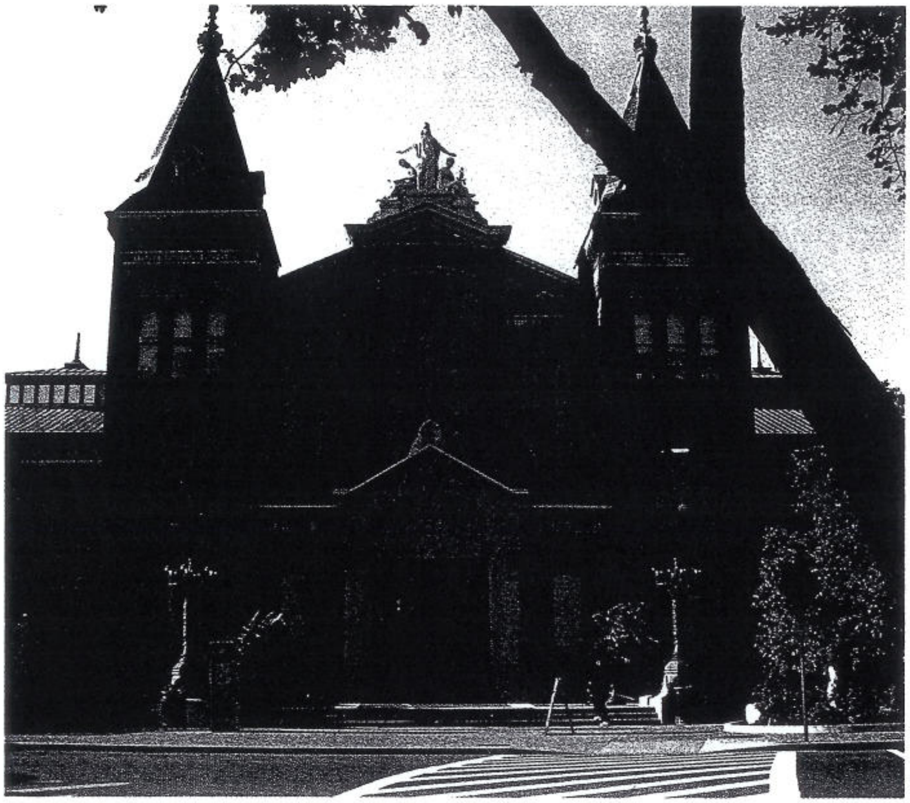


Photo by Kevin Guiffreda and Gary Johannsen, Smithsonian Institution

The north entrance of the Arts and Industries Building. This was the first building constructed for exhibiting objects from the Smithsonian collection.

The Smithsonian renovated the building in 1964–68 as the home of the National Portrait Gallery and the National Collection of Fine Arts, now called the Smithsonian American Art Museum. That renovation included installing a two-pipe, fan-coil HVAC system. Each spring, the system was switched from hot water to cold, and each fall the process was reversed. The system maintained an exhibition space environment that was about 40% to 45% RH on very cold winter days and around 50% to 55% RH in the summer. While there is a history of intermittent condensation on the north walls, this is most likely a result of the few times the old two-pipe, fan-coil HVAC system could achieve 50% RH in the building during a cold winter. Most of the time, the system kept the winter relative humidity between 40% to 45% RH. Ironically, the old HVAC system's lack of capacity actually prevented condensation damage to the interior surfaces of the north walls.

The Old Patent Office again is undergoing a massive renovation and HVAC retrofit. The new HVAC system is a forced-air system with four large central air-handling units and approximately 65 smaller units distributed throughout the building. The smaller units provide refined control in localized spaces. Finding space for ducts and pipes without disturbing the architectural details of the interior spaces is a real engineering challenge. Some spaces are not unlike the crypt of a gothic cathedral. Existing wall chases and false walls will be used to install vertical ducts. *Figure 2* illustrates how old fireplace flues are used to run pipe.

As a result of the lessons learned from the Renwick Gallery, the new environmental parameters of 45% RH ±8% RH and 70°F (21°C) ±4°F (2°C) are currently proposed for the Patent Office Building. A moisture barrier will be applied, but no insulation will be attached to the exterior wall. All the windows will be the thermal type.

The Arts and Industries Building

The Arts and Industry Building was designed by architects Cluss and Shultz and opened as the U.S. National Museum in 1881. This building has brick masonry construction throughout with a roof supported by wrought iron pinned trusses. The roof was covered with wrought-iron sheeting. To eliminate fire hazards, no wood was allowed in the construction. The building has a total of 185,000 ft² (17 200 m²) area, with 80,000 ft² (7400 m²) of exhibition space. The ceilings are 30 to 40 ft (9 to 12 m) above the floor. The original wrought iron trusses and iron roofing panels of the building's central rotunda and four major wings are visible from the ground level.

The Arts and Industry Building underwent a major renovation in the 1970s to restore the building to its original 19th century condition except that an HVAC system was added to control the interior environment. During this restoration, 2 in. by 4 in. (5 cm by 10 cm) wood spacer blocks and fiberglass insulation were installed over the original iron roof sheeting. A second roof of lead coated copper sheeting was applied over the new insulation. The wood spacer blocks were treated with fireproofing salts, which consisted of a mixture of ammonium sulfate, ammonium dihydrogen phosphate, and boric acid. No vapor barrier was installed.

The building experienced significant envelope degradation. In winter, water vapor migrated up into the wood and fiberglass insulation layer and condensed, saturating the wood and the fiberglass insulation. Then summer temperatures drove moisture out of the insulation. Relative humidity in the insulation layer reached around 80%, and the fireproofing salts caused water vapor to deliquesce onto the wood. A salt solution literally rained down inside the building.[10] The salts also accelerated corrosion of the iron materials, and flakes of rusted iron started falling from the ceiling 30 to 40 ft (9 to 12 m) above. *Figure 3* shows the degree of corrosion in the roof structure. These issues coupled with additional structural concerns, prompted the recent closing of the building.

Adding insulation to the roof of the Arts and Industry Building was an attempt to maintain a controlled interior environment. The insulation failure leaked enough heat to melt snow off the roof and may have saved the building from structural collapse during the severe winter of 2002–03. The design of the Baltimore and Ohio Railroad Museum in nearby Baltimore, was almost identical to the rotunda of the Arts and Industry Building. During that winter, the roof of the rotunda of the B&O Railroad Museum collapsed from 23 in. (58 cm) of accumulated snow.

Controlling interior environments is not often associated with maintaining structural integrity, but the two can be related in old buildings. When considering retrofitting an older building for exhibition purposes, it is important to consider what types of objects and resulting environmental requirements the building can accommodate. In the Arts and Industry Building, maintaining high relative humidity to protect display objects damaged the building. A variety of museum objects such as machinery, historic tools and trains can be safely displayed in lower winter relative humidity and the building would have easily accommodated this environment.

Summary

Preserving cultural and natural history collections and the buildings that contain them requires an integrated approach to indoor temperature and RH requirements. Research has shown no single environment satisfies requirements for all objects. However, the requirements for the buildings and the majority of collections fall within a fairly wide and sustainable set of conditions. Collections or items that require tighter control can be maintained within controlled microclimates.

Adopting an integrated approach that considers the needs of the building shell along with the needs of the collection can reduce degradation of the collections and in the buildings. It also establishes the importance of monitoring the reliability and effectiveness of the building systems that maintain the environmental conditions. Besides helping preserve buildings that are part of the nation's history, a more flexible approach to indoor environmental control lowers costs for initial construction or retrofit, reduces energy costs, and saves maintenance costs for replacing windows, façades, and related structural elements.

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