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journal

Copper Roofing:

The Original Green Roof

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Copper is a remarkable metal. It is resistant to corrosion, malleable yet strong and ductile, and ranges in color from bright salmon pink to soft grey-green. Highly durable, copper roofs can last 100 years or more with little maintenance. No small wonder, then, that copper has been used for centuries on some of our most noteworthy civic and institutional buildings as a distinctive roofing material. But are copper roofs solely relics of the past?

Known for its striking appearance, copper is also a strong environmental choice, given its longevity, recyclability, and low embodied energy.

Historically, copper was used widely for institutional and public buildings. Until the development of efficient aluminum ore extraction in the late 1880s, copper had few rivals in building construction. Today, prefabrication makes aluminum products relatively inexpensive, whereas copper roofing, which must be handcrafted, costs substantially more. Given that aluminum can be treated to mimic the color, if not quite the appearance, of copper, owners not subject to the dictates of a landmark authority may choose to forgo authenticity in favor of expediency.

True, the high initial cost of a new copper roof may make it impractical, even undesirable, for many buildings. Not all structures are intended to survive through the ages, and it makes little sense to cover a building designed to last twenty or thirty years with a roof that might last five times as long. Where sustainability, durability, and longevity are priorities, however, copper emerges as a top contender. In the modern climate of evolving product types and green design, it can be easy to forget that one of our most environmentally sound options is also one of our oldest.

Copper in Architecture: A History

Examples of sheet copper roofing in Europe date to medieval times, and the first discovery of naturally pure copper can be traced to Neolithic peoples around 8000 B.C. Saint Mary's Cathedral at Hildesheim has a copper roof said to date from the 1300s. In America, copper mining began in earnest in the mid-1700s, with copper derived from Maryland and New Jersey and, a century later, from Michigan and points west.

Juan Kuriyama, AIA, Senior Architect with Hoffmann Architects, has extensive experience designing and overseeing the rehabilitation of copper roofs, cupolas, and decorative elements. Project Manager William Hayes, Assoc. AIA develops copper restoration solutions that balance cost-effectiveness with durability.

Decorative Use

Copper's malleability permitted its ready adaptation to architectural ornamentation. Copper finials and weathervanes were popular during the late 1800s, and copper was commonly hammered or stamped into decorative details, moldings, friezes, and embellishments. Perhaps the most famous American example of monumental copper use dates from 1886: the *Statue of Liberty Enlightening the World* in New York City.

Today, the high cost of copper tends to preclude its ornamental use, but decorative copper is still used in historic preservation and conservation applications.

Roofing

In the years leading up to the American Revolution, sheet copper came into general use as a covering for ship hulls, which in turn led to its ready availability for roofing applications. Early examples of copper roofs include the New York City Hall (1763-1789), Maryland State House in Annapolis (1772-1793), Massachusetts State House in Boston (1795-1798), and the Old Christ Church in Philadelphia, the copper roof of which lasted from its initial construction in the 1830s until 1967, when it was finally replaced. The copper roof over the pediment of the First Bank of the United States in Philadelphia, built between 1795 and 1797, is still intact today, over two centuries later.

Given the astounding endurance of historical copper roofs, it's reasonable to conclude that a well-designed and skillfully installed copper roof is worth the up-front investment. Compare the lifespan of a copper roof with that of a pre-fabricated metal roofing system warrantied for 35 years, or with the even shorter lifespans—and high maintenance demands—of bituminous and synthetic materials.

Embodied Energy and Environmental Impact

The "embodied energy" of a material refers to the total amount of energy consumed during that material's lifespan, including extraction, processing, manufacture, transport, installation, maintenance, and disposal. Compared with other metals, copper requires a relatively small expenditure of energy to extract and process.

Embodied energy comparisons should consider the life span of the material. A single-ply or built-up low-slope roof might claim to have a lower embodied energy than a copper one—that is, until material lifecycle is taken into consideration. With an expected service life of 100 years or more, a copper roof has four times the lifespan of a standard 25-year assembly. Therefore, the embodied energy of a copper roof should more accurately be compared with that of *four* 25-year roof assemblies. In these terms, copper emerges as the clear energy champion.

Durability isn't the only factor that makes copper a strong choice, environmentally speaking. Green building rating systems, including Leadership in Energy and Environmental Design (LEED), now incorporate *life cycle assessment (LCA)* data into their certification scores—and with good reason. LCA is a method of evaluating a product's environmental impact across its lifespan.

Embodied energy is part of an LCA calculation, but the assessment also considers reuse and recyclability. Here, too, copper has an advantage over other roofing materials: it is recyclable in all forms. Salvaged copper, architectural copper, and the cuttings and filings produced during finishing can all be re-incorporated into new copper products. Such recycled copper isn't restricted to low-grade materials; in the U.S., architectural copper is made primarily from recycled content, with some products made from as much as 90% recycled material.

Copper's impressive lifespan and nearly infinite recyclability derive from its unique material properties, which allow the metal to retain its appearance, strength, malleability, and corrosion resistance for multiple uses across the centuries.

Beyond roofing, copper is also used for ornamentation. Restoration of this copper eagle atop a 1929 high-rise involved off-site and on-site repair, cleaning, and reconstruction.

The Roof Runoff Scare

In 2000, the City of Palo Alto, California commissioned a study on the environmental impact of stormwater runoff from copper roofing, which precipitated a city ordinance prohibiting the installation of copper roofs and gutters on both new and existing buildings. A number of other jurisdictions across the country followed suit.

The study raised a number of questions. How much copper was getting into the environment, and what were its effects? Could copper runoff be harmful to humans? Were copper roofs dangerous?

These and similar concerns plagued the copper industry. However, research has since emerged that calls into question the Palo Alto study's conclusions. One such study appeared in 2008 in the *New Zealand Journal of Marine and Freshwater Research*, which suggested "an overestimation of bioavailable copper" in previous reports, including the Palo Alto study. The authors found that the effective copper concentration in waterways is actually less than had been assumed, due to the binding of free copper ions into nontoxic hydroxide and carbonate complexes.

Recognizing that not all forms of copper in the environment are harmful, the U.S. Environmental Protection Agency (EPA) revised its water quality criteria for copper, now basing its standards on bioavailability, not just concentration. Reducing bioavailable copper – that is, copper that can be absorbed by organisms – has since become the aim of environmental watchdog groups and copper industry associations alike.

Research is also currently underway to determine the effectiveness of on-site stormwater treatment systems, such as rain gardens, that filter runoff naturally. As runoff flows through these systems, free copper ions bind to conduits and organic debris, reducing the bioavailable copper concentration. Runoff that might have toxic levels of copper at the roof downspout may not be hazardous once it reaches the watershed.

As the results of further research emerge, the copper industry, the EPA, and local governments will continue to revise recommendations for stormwater treatment and copper roofing. For the time being, architects and engineers will have to stay current with regulations and design accordingly. ■

Uses in Roofing

Traditionally, there are three types of copper roofing, each with its own distinct aesthetic qualities and applicability for a given roof condition.

Flat Seam

Unique to copper roofs, flat seam construction is generally reserved for low-slope roofs or curved surfaces, such as domes or vaults. Cold-rolled copper sheets are folded over at adjacent sides, with copper cleats installed in the seams. Typically, the longitudinal seams are continuous, whereas transverse seams are staggered. For slopes of 3"-in-12" or less, the flat-locked seams are soldered to improve water-tightness.

Standing Seam

Pre-formed or field-formed pans are used to create standing seam copper roofing. One side of each pan is formed longer and folded twice over the adjacent pan, joining the panels together. These double-locked standing seams run parallel to the roof slope, with fixed copper cleats securing the roofing to the structural deck.

Batten Seam

With its characteristic box-shaped seams, batten seam construction is commonly used on domes, barrel vaults, and cupolas to create a dramatic roof line. Like standing seam roofs, batten seam construction positions copper pans parallel to the roof slope. Panels are separated by wood battens, which are covered with copper batten caps that are loose-locked to adjacent pans to accommodate expansion and contraction.

In addition to its use as a roof cladding, copper is also widely used for roof flashings, gutters, downspouts, and cornices, in conjunction with other roofing types and materials. Its resistance to corrosion and its malleability allow copper to be readily shaped to accommodate intersections, bends, and curves without failure.

Aesthetics

Regardless of type, copper roofs both new and old are standouts in any building skyline. Beyond practical

Unusual conditions, such as this combination of soldered flat-seam roofing with steep-slope batten-seam, demand customized designs.

considerations, such as low life-cycle costs, salvage value, longevity, and low maintenance demands, copper is often selected for roofing because of its distinctive color and texture. With natural weathering, copper changes from the color of a new penny through a series of dull brown shades to a striking blue-green. Depending upon the climate and application, copper roofing weathers and changes hue gradually over time, lending each copper-clad roof a unique appearance.

Types of Copper

Soft copper can readily be cast, extruded, punched, or hammered, making it ideal for ornamental use. However, it is not strong enough to be used for construction purposes beyond decorative details.

Cold-rolled copper is used for roofing and flashing. Less pliable than soft copper, it is nonetheless sufficiently malleable to bend around penetrations and intersections, and it is much stronger than copper used for decorative purposes.

Copper alloys include bronze (copper and tin) and brass (copper and zinc). Both are compatible as fastener materials for securing copper roofing.

Lead-coated copper, which is cold-rolled copper coated on both sides with lead, is used for roofing and flashings. Development of lead-coated copper was prompted by the desire for roofing and flashing material with the appearance and properties of lead, at a lower cost and with less weight. Lead-coated copper tends to be more compatible with porous facade materials, such as marble and limestone, which are easily stained by copper runoff.

Patina

An active metal, exposed copper reacts with the environment to form a protective *patina*, actually a thin layer of corrosion. On steel, such corrosion (rust) can completely consume the metal. Not so for copper, where the oxidation layer forms a thin, stable coating that protects against further degradation. Ironically, copper corrosion is what makes it corrosion-resistant.

In the presence of moisture, copper combines with airborne sulfur compounds to form a protective copper sulfate coating. Once fully formed, the sulfate patina significantly increases the durability and service life of copper roofing and flashing by shielding it from atmospheric contaminants and corrosion.

Patina formation is highly dependent on climate. In industrial areas, where the burning of fossil fuels increases the amount of sulfur dioxide in the air, a patina may form in as few as five to seven years. In rural areas, it may take twice that long. In dry climates, there may be insufficient moisture for the chemical conversion process to take place, and a sulfate patina may never form.

Efforts to accelerate the patina process using acid sulfate or acid chloride treatments to quickly achieve the familiar blue-green color of aged copper have yielded unreliable results. Variables such as surface preparation, application method, humidity, temperature, and wind velocity make the chemically-induced patina process more of an art than a science. Typical problems include lack of color uniformity, staining of adjacent materials, and poor adhesion.

The intermediate oxide and sulfide conversion films in the natural patina process, characterized by hues of light reddish brown to deep chocolate, may also be realized through chemical means. Aqueous solutions of ammonium sulfide, potassium sulfide, or sodium sulfide applied to copper can achieve these "statuary" or "oxidized" finishes, in a range of colors depending upon the concentration and number of applications. However, results are far from consistent.

Deterioration and Failure

Unfortunately, no matter how beautiful a copper roof is, it will, like all roofs, eventually fail.

Corrosion. Although the patina provides protection against corrosion, copper is susceptible to attack by alkalis, ammonia, some bituminous roofing cements, masonry cleaners, sulfate-reducing bacteria, and acid rain. The longer acidic moisture is in contact with the copper (*dwell time*), and the lower the pH of the moisture, the more likely damage to the copper will result.

Acid rain that falls on many common roofing materials, such as tile, slate, asphalt, or wood shingles, generally is not neutralized, as it is when flowing over limestone or granite. When this runoff is collected and concentrated at a copper flashing or gutter, the copper may deteriorate before it has a chance to develop a protective patina. If the leading edge of roof shingles rests directly on copper flashing, capillary action can exacerbate corrosion by retaining acidic moisture at the edge of the shingle. The resultant deterioration of the copper flashing is known as *line corrosion*. The solution is to raise the leading edge of the shingles using a cant strip to break the capillary action and reduce acidic moisture dwell time at the copper flashing.

Abrasion and erosion. Copper is a relatively soft metal, and it is therefore susceptible to damage. Rough sheathing boards, cables, foot traffic, excessive handling, dripping water, hail, and other abrasive forces can wear away at the copper and lead to premature failure.

Galvanic action. When dissimilar metals are in contact, negative ions from one metal are deposited onto the other, causing the less stable metal to corrode. High on the *galvanic index*, copper is a "noble" metal and therefore not prone to corrosion. Metals that are lower on the galvanic index, including steel, zinc, and aluminum, will corrode when in contact with copper in the presence of an electrolyte (such as salt water). Aluminum nails mistakenly used to secure copper cleats will eventually corrode due to galvanic action.

Use of electrolytically compatible materials is strongly recommended for copper roofing. If contact between dissimilar metals cannot be avoided, the surfaces should be painted with a zinc chromate or bituminous coating or separated with non-absorptive tape or gaskets.

Metal fatigue. When deformed repeatedly by forces such as wind uplift or restrained expansion and contraction, copper, like most metals, will develop faults. If the deformation is within the copper's *elastic range*, that is, small enough for the copper to recover its original shape, these faults may not be noticeable at first. As the metal undergoes thousands of such deformations over its lifespan, flexure (bending back and forth) can eventually lead to characteristic star-shaped cracks and fractures. Metal fatigue is especially pronounced at sharp corners and areas where wind uplift is particularly strong.

The good news is that all of the above sources of premature failure are avoidable. Unfortunately, incorrect design, poor detailing, incompatible materials, and inexpert repairs can substantially shorten the lifespan of a copper roof.

Restoration

For landmark and historic structures, preservation ordinances may limit rehabilitation options to restoration of the existing copper or replacement in kind. Check with the authority having jurisdiction over historic buildings to determine whether the roof is subject

Should You Coat Your Copper Roof?

Copper roof rehabilitation is expensive. When faced with the choice between replacing a copper roof, at a cost of hundreds of thousands of dollars, or applying a coating over the existing copper to eke out a few more years of life, many owners opt to defer the problem. The trouble with this mindset is that it is a case of "throwing good money after bad;" the owner winds up paying for coating (and recoating) and, likely, repairs to a leaky building interior—on top of eventually replacing the failed roof.

Coating a copper roof creates an ongoing maintenance demand. While a copper roof might last a century, the lifespan of a typical coating is roughly ten years, necessitating frequent recoating and even more frequent touch-ups. Rather than protect the copper, coatings can actually accelerate corrosion, as moisture becomes trapped between the coating and the metal. Because coating removal destroys the finish of the copper, it's difficult to return to an uncoated state. Once a copper roof has been coated, there's often no going back.

At a tiny fraction of the price of a new roof, coating has a definite appeal as a temporary fix. But before hiring a contractor to coat a copper roof, consider that, far from temporary, coatings can create permanent problems. The price may not be right, after all. ▪

to such regulations.

Deteriorated copper roofing should be evaluated by an experienced design professional to determine whether it can be salvaged. If not, damaged areas should be removed and replaced with new copper of the same temper and ounce weight. Adequate provision should be made for expansion and contraction, and all fasteners and clips must be made of electrolytically compatible materials, such as copper, brass, or certain stainless steel alloys.

When replacing portions of a patinated copper roof, it may be necessary to treat the entire roof to allow it to repatinate uniformly. A diluted solution of phosphoric and nitric acids is applied to the copper and then neutralized with sodium bicarbonate and ammonium oxalate. After rinsing, the copper should be treated with a thin coat of carnauba wax, which gradually wears off, allowing the patina to form evenly.

With proper design and detailing, sealants are generally unnecessary on copper roofs. The lifespan of copper is significantly longer than that of most sealants. If sealant is used on a copper roof, it must be routinely inspected, maintained, and replaced, adding substantially to maintenance demands. Where appropriate, such as on low-slope flat-seam roofs, solder should be used rather than sealant. For rehabilitation applications, it is preferable to open the seam, remove the existing solder, and re-form and solder the joint.

Solder is not the solution to all copper repair problems, however. Because the coefficient of expansion for lead-tin solder is different from that of copper, solder used to fill stress cracks will eventually break away. If cracking and metal fatigue are widespread, it may be time to consider roof replacement.

Application of lead-tin solder to a flat-seam copper roof.

Copper Roof Replacement Design

A successful reroofing project begins with good design. The first step is to evaluate existing roof decks to determine whether they can support a copper roof installation. For roof assemblies that use cleats secured directly to the deck, such as standing seam roofs, the roof deck must be capable of sustaining design wind conditions. Batten seam roofs, with wood battens secured to the deck by bolts or anchors, are generally compatible with any deck type. Pull testing of fasteners is recommended.

Surface preparation is critical to the lifespan of the roof. Copper is easily damaged by rough surfaces, projecting nail heads, and other flaws. To cushion the copper sheets, an underlayment, often asphalt-saturated roofing felt, should be secured to the deck surface with copper or brass fasteners. To prevent the copper from adhering to the underlayment, especially when high roof temperatures soften the asphalt in the felt, place a slip sheet of rosin paper between the underlayment and the copper sheets.

Code requirements now typically dictate addition of an ice dam membrane at eaves, rakes, ridges, valleys, hips, and along the roof perimeter. Positioned below the underlayment, this rubberized asphalt membrane serves as a secondary waterproofing protection. Where feasible, incorporating the membrane across the entire roof area can provide additional assurance against water infiltration.

Typically, copper roofing is constructed using 16- or 20-ounce cold-rolled copper sheets in 18- to 24-inch widths. Wind uplift, roof pitch, and roof system type dictate the ounce weight and dimensions of the copper sheets, which are pre-formed or field-formed into pans. "Short pans" are ten feet long or less, while "long pans" are over ten feet. When using long pans, it's important to accommodate additional expansion at the ends of the pans when determining cleat design and spacing.

Standard industry details for copper roofs are a good place to start, but specific field conditions often necessitate design details that go beyond boilerplate guidelines. An architect or engineer should consider the interrelationship between the roof and other building elements, as well as code requirements, site conditions, roof orientation and exposure, climate, roof slope, drainage, penetrations, accessories, roof configuration, and other building properties.

Going Green

When correctly designed and installed, copper roofing provides reliable, water-tight protection from the elements that is as elegant as it is ecological. Beyond its distinctive patina, copper is "green" in other senses, too: its longevity, recyclability, and low embodied energy make it a sound environmental option, as well as a desirable aesthetic element. Copper roofing isn't limited to historic applications; a number of

(continued on page 8)

representative projects

Copper Roof Rehabilitation

A long-lasting and durable metal, copper can withstand many years of service. Unfortunately, copper roofs don't last forever—especially when inexpert repairs, poor detailing, and atmospheric pollution conspire to degrade the roof prematurely.

Hoffmann Architects has the experience to design appropriate restoration strategies—and to identify a roof that is ready for replacement. Our architects and engineers begin with a thorough evaluation to determine the integrity of the existing roof. In consultation with the owner, we develop a rehabilitation strategy that serves the needs of the structure while meeting budgetary, scheduling, and aesthetic objectives.

Hoffmann Architects has developed copper roof solutions for diverse structures, including:

The Bushnell Memorial Hall
Hartford, Connecticut
Copper Roof Restoration

New York Stock Exchange
New York, New York
Copper Roof Investigation and Repair

St. Joseph Church
New Haven, Connecticut
Cupola and Bell Tower Roof Repair

Worcester Polytechnic Institute
Washburn Shops
Worcester, Massachusetts
Cupola Restoration

Sanders Classroom Building at **Vassar College** in Poughkeepsie, New York. *Copper Roof Replacement.*

Wellesley College
Tower Court Residential Complex
Wellesley, Massachusetts
Copper Roof Replacements

Lockwood-Mathews Mansion Museum
Norwalk, Connecticut
Lead-Coated Copper Roof Restoration

Columbia University
Earl Hall
New York, New York
Copper Roof Replacement

Private Residence
East 67th Street
New York, New York
Copper Dormer/Cladding Consultation

Lehigh University
Packer Memorial Church
Bethlehem, Pennsylvania
Copper Roof Investigation and Repair

Smithsonian Institution
National Portrait Gallery
Washington, District of Columbia
Copper Roof Replacement

48 Wall Street
New York, New York
Cupola and Eagle Restoration

Church of St. Augustine in Larchmont, New York. *Copper Roof Restoration.*

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(continued from page 6)

contemporary buildings turn to copper for its striking appearance and its ability to accommodate complex designs.

Because of its comparatively high initial cost, copper is often passed over in favor of less expensive roofing materials. Over the long term, though, copper's durability and low maintenance requirements make it a cost-effective option for buildings designed to stand the test of time.

For historic structures, restoration can further extend the lifespan of aging copper roofs, provided repair measures are carried out appropriately. Inexpert repairs often do more harm than good, accelerating deterioration or permanently damaging the copper. In many cases, the only way to undo the damage is to replace the roof.

Before repairing a copper roof—or installing a new one—be sure to consider factors specific to the building and situation, with design details customized to accommodate field conditions. No matter the application, a copper roof must be designed to meet the needs of the individual structure if it is to live up to its potential. ■

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