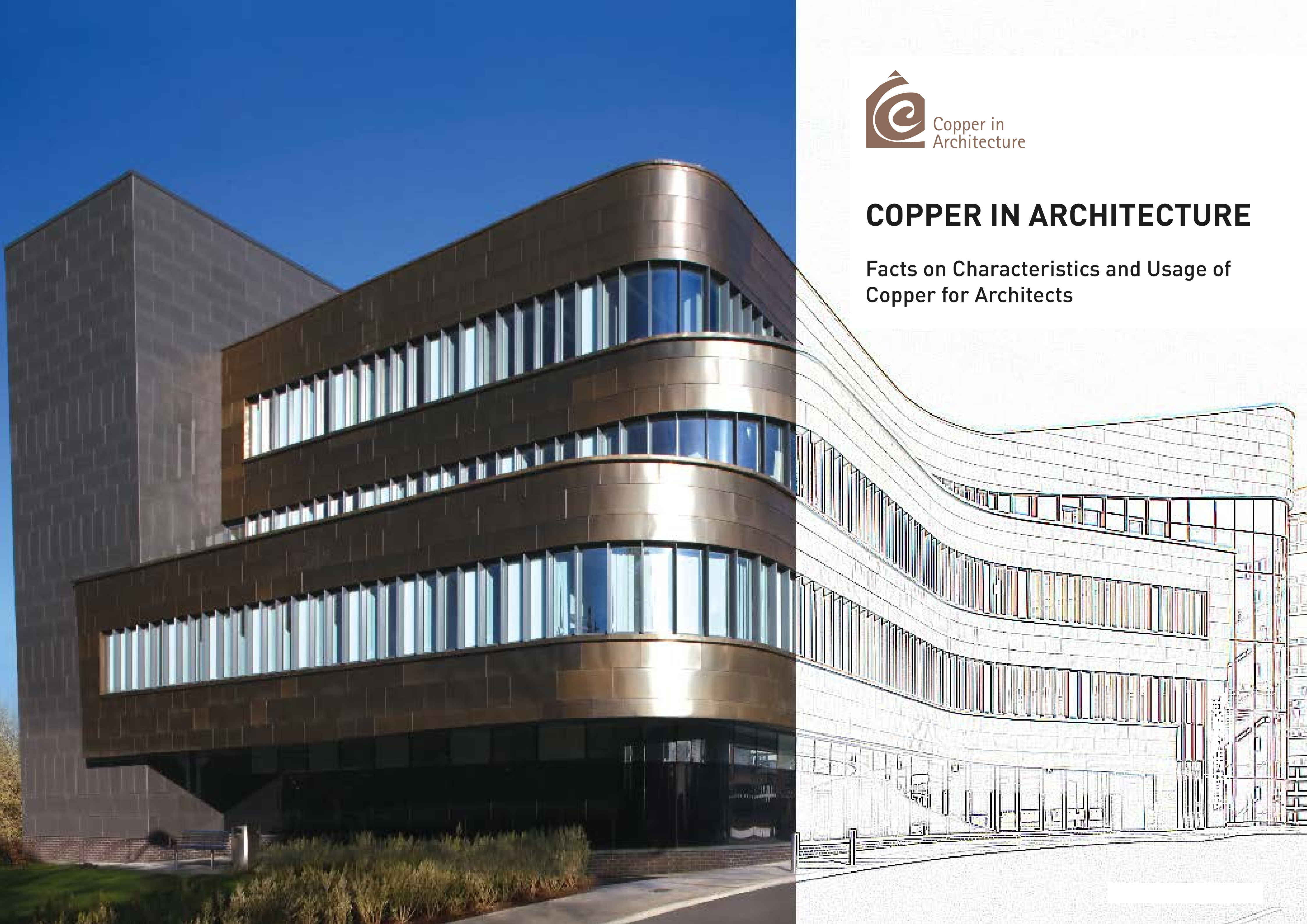
Copper in Architecture

COPPER IN ARCHITECTURE

Facts on Characteristics and Usage of Copper for Architects



INTRODUCTION

Copper was one of the first metals used by mankind and has a very long tradition in architecture – the Romans used golden bronze to cover the roof of the Pantheon and many of the great churches of medieval Europe were covered with opper. Its distinctive green patina still plays a major part in the skylines of most European cities, demonstrating timeless and enduring qualities.

Nowadays, copper can provide a complete external skin, wrapping around complex building forms with material continuity. Surfaces can be flat, curved or faceted and used at any inclination or pitch, and in any environment. But also, many designers have been keen to explore new manifestations of copper. In addition, there is growing interest in the use of copper for interior design.

There are many reasons to consider copper and copper alloys for architectural projects and not simply because their unique properties make them extremely malleable and versatile building materials to work with. The broad range of architectural possibilities offered by this natural material and its alloys allows for singular design, and conventional thinking to be challenged.

Visually, the aesthetic qualities of copper materials add character and quality to any project, whilst lightweight nature of their structure permits creative and cost-effective structures to be designed.

The natural development of a patina, with colours changing from red to chocolate brown, and eventually to the distinctive light green, is a unique characteristic of copper. Prefabricated systems offer a wide variety of solutions, while perforated and expanded copper sheets add new possibilities for transparency.

Copper Concept

COPPERCONCEPT.ORG

Copper is introduced worldwide as modern material for roofing and cladding applications. Some of the world's most distinguished modern architects have relied on copper including Frank Lloyd Wright, Alvar Aalto, Renzo Piano, Herzog & de Meuron and Foster & Partners. To see copper references in contemporary architecture visit copperconcept.org or scan QR code.

In these days when ecological considerations in relation to the choice of construction materials have joined aesthetic and economic aspects, the impressive sustainability and environmental credentials of copper have been clearly demonstrated. Copper products include high levels of recycled materials, saving on energy and greenhouse gases, and contributing to the circular economy. In addition, copper scrap can be re-used ad infinitum without any loss of performance or qualities.

WHY COPPER?

1. natural material
2. environment-friendly
3. maintenance-free
4. durable, long lasting
5. 100% recyclable
6. corrosion-resistant
7. non combustible
8. waterproof
9. proven architectural material
   - malleable, not rigid
   - lightweight
   - homogeneous material
   - timeless, living surface
   - colorful and varied
   - creative and unique

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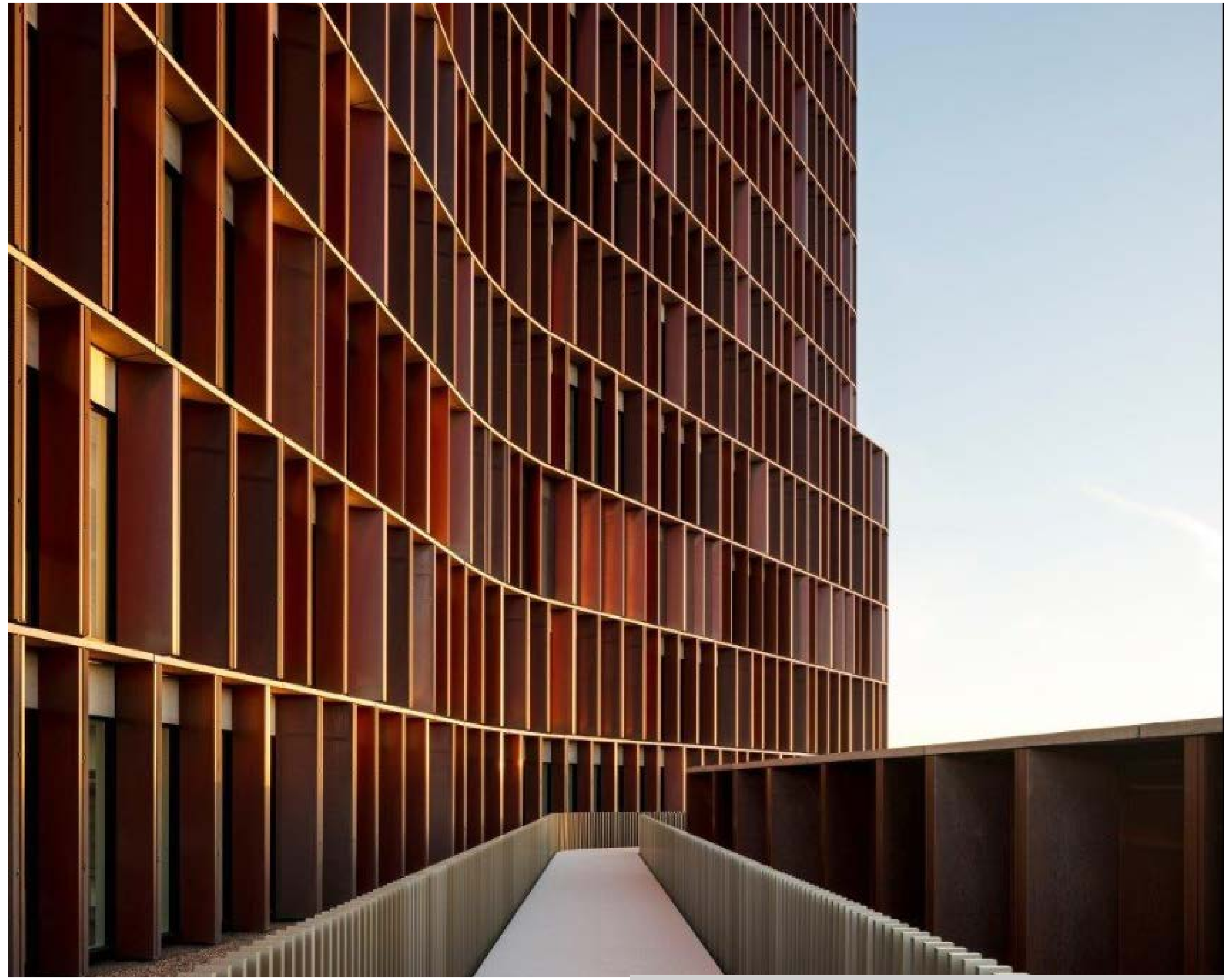


Front Cover: The Christie, Manchester, UK
AFL Architects

Back Cover: Novotel Paddington, London, UK
Dexter Moren Associates

Maersk Building, Copenhagen, Denmark
Architect: C.F. Møller
Photo © Adam Mørk

The facade is built up in the form of a grid comprising storey-height window fields that break up the building's large scale.

CHARACTERISTICS

NATURAL OCCURRENCE OF COPPER AND ITS ROLE IN HUMAN HEALTH

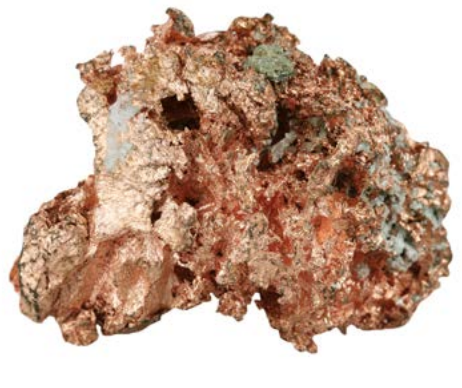
Copper exists naturally in the environment, being an essential trace element for all living organisms. Copper is needed for growth, development and functioning of the human body and must be obtained from food and water as part of a balanced diet. It is regulated by homeostasis and does not accumulate in the food chain.

As a naturally-ocurring element, copper can be found in the Earth's crust – at a concentration of about 67 parts per million – as well as in freshwater and seawater, from minute trace element levels through to rich mine deposits. It is not persistent, bio-accumulative or toxic to the environment and should not be mistaken with artificial chemicals or toxic heavy metals, which can accumulate in humans, sea life and plants. Copper is heavy by its density (8,94 g/cm^3), but this has nothing to do with hazard or environmental properties.

FIND OUT MORE ON THIS TOPIC
https://copperalliance.eu/about-copper/

While copper has always been naturally present in all environments, anthropogenic (man-made) emissions have been added in the last centuries – for example through the wear of brake pads or the use of salts in agriculture – and it is necessary to know whether these „new" additions of copper could be a matter of concern.

Copper sheet exposed to atmospheric conditions gradually form a protective surface layer, also known as patina, that extends the service life of the material. This surface is complex, very durable and stable. So stable that only a very small amount of material is lost over a long period of years of exposure to rain and other forms of precipitation.



The copper compounds that form the patina are poorly soluble and very different from water soluble copper salts. As a consequence of this low solubility, a very small fraction of the patina is released from the copper surface during precipitation. This is called the runoff. See more in colour and patina chapter.

It is estimated that only 1% of the overall amount of copper that enters into the environment from anthropogenic sources can be attributed to copper from architectural surfaces. Research also shows that the bioavailable portion of copper in the runoff is quickly and considerably reduced as copper ions react with the environment – for example, in contact with solid surfaces such as pavement, limestone or rainwater pipes – forming non-available complexes and compounds in the immediate proximity of the roofs and facades. Reactions with organic matter, such as decaying leaves, could reduce the bioavailable portion even more.

This is indicated by the fact that runoff and discoloration appear always on a relatively short length, after rain water from gutter touches pavement, following the direction of the water. Where copper content of rainwater run low, these strips end, because water doesn't transport copper anymore.

Much scientific research has demonstrated that extensive use of copper to clad buildings is environmentally safe. In addition, studies evaluating the dermatological and oral effects of a number of copper compounds have also demonstrated that copper roofs and facades do not pose any harm to human health. In conclusion: copper runoff from roofs should not be a matter of concern.

COPPER, THE RECYCLING CHAMPION

In 2015, 3.7 million tonnes of copper were used in the EU28, with around half of that need met by recycling.

Source: Fraunhofer ISI

Most copper is produced from open-pit mines and reserves are plentiful with deposits worked in all five continents. Usually, mines operate with copper concentrations of between 0,2 and 1%, although some of the richest ore bodies can contain 5-6% copper. Copper is extracted from ore, mainly copper sulphides, and transformed through various processes into high-purity copper (99,99%).

Another important source of copper is recycled scrap. Copper is one of the few raw materials which can be recycled ad infinitum without any loss of performance; there is no difference in the quality of recycled copper (secondary production) and mined copper (primary production).

European copper products for architectural applications are produced including high levels of recycled materials, typically 85% or more with scope up to 100%. As well as helping to satisfy the annual demand, recycling copper is a highly eco-efficient way of reintroducing a valuable material back into the economy, saving energy and reducing CO_2 emissions.

SUSTAINABILITY AND GREEN CREDENTIALS

European copper products for architectural applications are produced according to EN 1172 specifications in world class plants with strictly monitored environmental performance and well-established recycling routes. They include high levels of recycled materials, typically 85% or more with scope up to 100%, saving on energy and greenhouse gases, and contributing to the circular economy. Copper sheets' (copper massive) interaction with the environment has been assessed under the European REACH chemical policy and has no classification/restriction.

Copper occurs naturally as part of the cycle of metals which form in nature, being used by society and returning to nature or being recycled for further use by society. The economic value of copper drives recovery and recycling, not just of copper but also many other materials during dismantling and demolition. Copper is long lasting, can be used in challenging environments and installations are, for the most part, maintenance free resulting in savings in resources, cleaning chemicals and costs.

The recycling of copper is a well-established practice and its extent follows overall consumption patterns. This is due to the relative ease, compared with other metals, of re-using both processing waste and salvaged scrap from eventual demolition, as well as the incentive of copper's value. Copper can be recycled again and again without any loss of performance or qualities.

The copper industry – from mining to fabrication – spends in the region of 30% of capital expenditure on improving environmental performance. The processing of copper is on a „Continuous Improvement Program" to service customers and shareholders, and comply with current market and policy needs. The industry is responding to the European Commission circular economy initiative and looks forward to receiving more scrap for re-use as the economy becomes more efficient at managing material use throughout its life – especially towards end-of-life.

All these key environmental credentials of copper products can be a decisive argument in favour of use in buildings requiring LEED, BREEAM or DGNB certificates, which are increasingly in demand, particularly for public buildings.

It is also worth noting the importance of environmental rating tools for investment decisions and their usefulness for looking at the whole supply chain and determining where the greatest improvements in environmental performance can be made for a given product. Unfortunately, they have many inadequacies when used to make comparisons. For comparisons to be worthwhile, accuracy of the tool and the methodology behind it need to be both robust and fair when comparing two products of very different compositions and implementations, even if for the same use.

For simplification, too many tools have used non-robust and unfair assumptions, resulting in extremely misleading comparisons. Easy mistakes to make include:

- comparing energy and cost per tonne rather than per m² of material, thus misrepresenting thinner, lighter materials such as copper
- missing the cost and environmental benefits for complete construction of lightweight materials
- using inappropriate life span estimates, thus adding 'energy use' for unnecessary replacement
- disregarding today's efficient recycling practices.

As a recommendation, architects should focus their comparisons on: Primary Energy; Ozone depletion potential; Acidification potential; Eutrophication potential; and Photochemical Ozone Creation potential. These are impact categories that are well-known, global and mature – rather than other lesser known, non-robust and erroneous comparative indicators, especially in the field of toxicity, land use and resource use.

FIND OUT MORE ON THIS TOPIC
https://copperalliance.eu/benefits-of-copper/

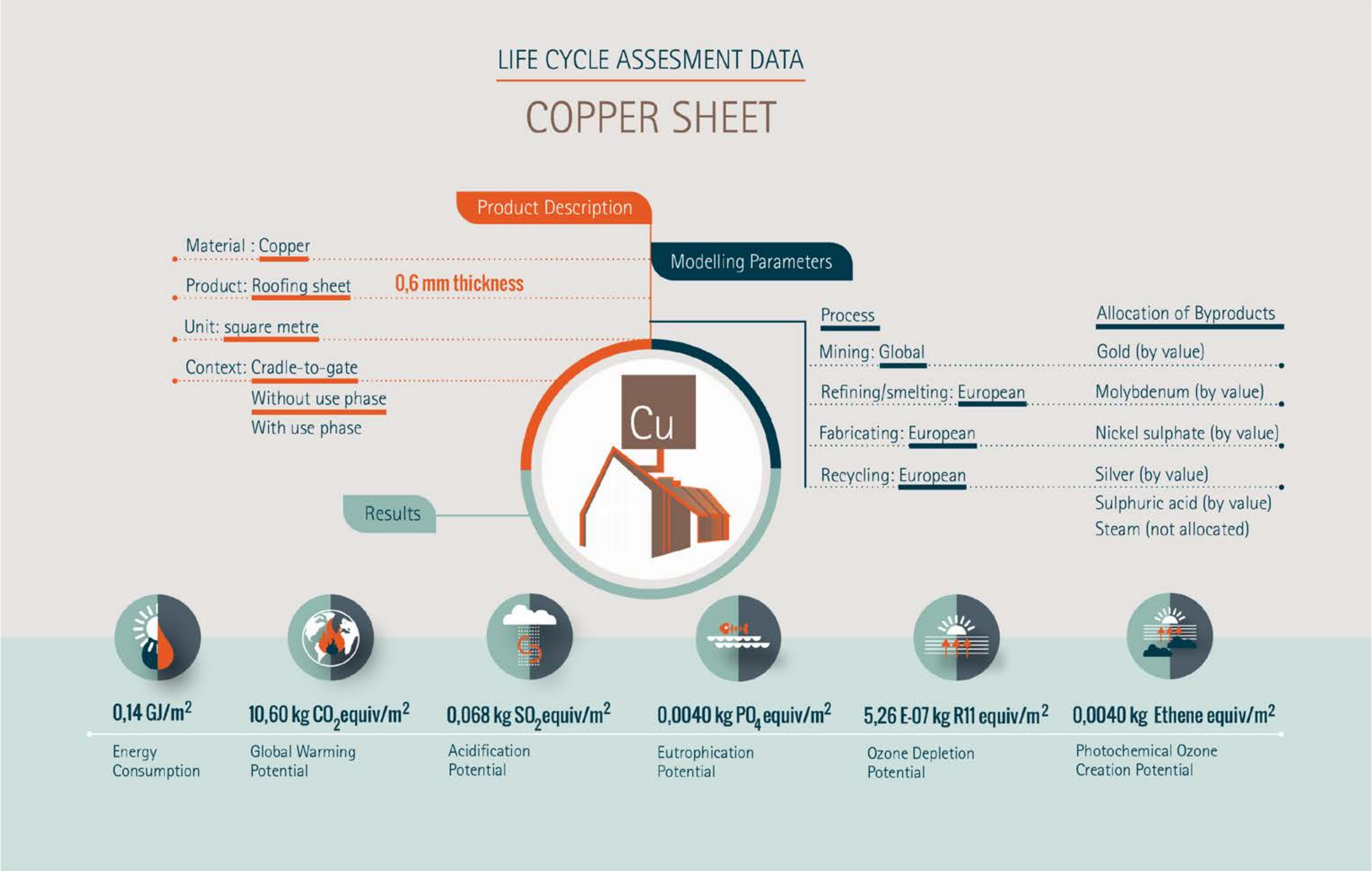
The Eden Project: The Core, UK
Architect: Grimshaw Architects
Photo © Peter Cook

It is the education centre for the largest plant enclosure in the world, built in the lightest and most ecological way possible

GREEN BUILDING

GREEN BUILDINGS ON COPPER CONCEPT

To discover more project examples and information on green buildings go to copperconcept.org/en/references and turn on "green building" filter or scan QR code.



County Administrative Building, Turku, Finland
Architect: Risto-Veikko Luukkonen and Helmer Steenroos
Photo © Robert Pinter

The building has been re-clad using the very same copper material originally installed in the 1960s - an impressive demonstration of the extremely long-term value of copper as an asset to buildings.

London 2012 Handball Arena - Copper Box, London, UK
Architect: Make Architects
Photo © Make

A key feature of the building is the 3,000m² copper cladding, which has 65% recycled content. Architectural copper can be produced out of 100% recycled content and can be recycled again in the future.

PHYSICAL AND MECHANICAL PROPERTIES

The European Standard EN 1172 - „Copper and copper alloys: Sheet and strip for building purposes" specifies the composition and mechanical properties for copper and copper alloy sheets and strips used in building construction.

Copper is generally applied as a lightweight covering, requiring less supporting structure than many materials. With a low thermal expansion value, properly designed copper roofs and facades minimise movements due to thermal changes, avoiding deterioration and failure.

As evidenced by the following copper-clad projects, copper can be worked at any temperature and does not become brittle in cold weather:

- Capanna Regina Margherita - the highest mountain hut in Europe, placed at 4554 m, near the top of Monte Rosa Massif.
- Svalbard Science Centre - located in the north of Norway, where in winter months the average low temperatures fall below -10°C.

In addition, the high melting point of copper ensures that it will not „creep" or stretch in hot weather, as some other metals do.

Copper is also classified as A1 (non-combustible material) in accordance with EN 13501-1; the highest ranking available. Copper and copper alloy sheets and strips are non-combustible and release neither fumes nor toxic gases. In case of fire, experience proves that copper acts as a barrier against the propagation of fire.

MECHANICAL PROPERTIES									
Designation			Tensile strength		0,2 % proof strength		Elongation	Hardness	
Material		Material condition	R_m N/mm²		$R_{p0,2}$ N/mm²		$A_{0\ mm}$ %	HV	
Symbol	Number		min.	max.	min.	max.	min.	min.	max.
Cu-DHP CuZn0,5	CW024A CW119C	R220	220	260	-	140	33	-	-
		H040	-	-	-	-	-	40	65
		R240	240	300	140	-	8	-	-
		H065	-	-	-	-	-	65	95
		R290	290	-	250	-	-	-	-
		H090	-	-	-	-	-	90	-
CuSn0,15	CW117C	R250	250	320	200	-	9	-	-
		H060	-	-	-	-	-	60	90
		R300	300	370	250	-	4	-	-
		H085	-	-	-	-	-	85	110
CuAl5Zn5Sn1	CW309G	R400	400	-	170	-	45	-	-
		H080	-	-	-	-	-	80	-
CuSn4	CW450K	R290	290	390	-	190	40	-	-
		H070	-	-	-	-	-	70	100
CuZn15	CW502L	R310	310	370	200	290	10	-	-
		H090	-	-	-	-	-	90	115

No other roofing material exists with similar elongation. Accordingly, copper is extremely formable, which makes it the most appropriate material for cladding complex forms.

Copper products (sheets and strips) can be supplied in a range of conditions or „tempers". These conditions are designated in the Standard EN 1172 as soft (R220), half-hard (R240) or hard (R290). The letter R represents the tensile strength (in N/mm²): the higher the value, the stronger and harder the material.

While the tensile strength of the so-called soft copper is lower, it is easily deformable and its minimum flexural radius value is smaller. Half-hard copper is stronger, but less flexible and less bendable.

For difficult-to-clad forms, where bending of sheets, drawing-out of seams, arching or bossing is required, it is better to use soft material, while in the case of continuously plane surfaces, manufacture of cassettes and profiled sheeting half-hard condition is advised.

The strength and hardness of copper can also be increased by alloying – that means that copper alloys have less workability (bending with low radius of curvature) but higher rigidity. They fit better for facades, where perfect planarity and resistance to impact and wear are required, and the material must be able to support its own weight.

The coefficient of thermal expansion of copper is one of the lowest among metal cladding materials: 1 m has a thermal expansion of 1.7 mm with a temperature difference of 100 °C.

PHYSICAL PROPERTIES OF COPPER	
Density	8.94 g/cm³
Melting point	1083°C
Coefficient of thermal expansion	1,7 mm/m ΔT=100K
Modulus of elasticity at 20°C	132 kN/mm²

Svalbard Science Centre, Norway
Architect: Jarmund/Vigsnaes Architects
Photo © Nils Petter Dale

The insulated copper-clad skin is wrapped around the building, creating an outer shell adjusted to the flows of wind and snow passing through the site.

LONGEVITY

Performance, maintenance, service life, and recovery value from recycling are factors that determine the cost of building components. Using life cycle costings, copper stands out as a very cost-effective material for roofing and cladding, due to its durability, maintenance-free nature and ultimate salvage value.

Because of its indefinite life and unique characteristics, copper is often used on landmark projects and might be wrongly perceived as an expensive building material. However, the existing cost competitiveness of copper results in its use on an ever wider variety of building types.

In case of copper roofing and cladding, investment costs are paid once, and no expenses are required later. The lifetime of these structures can surpass the potential working life of buildings and no maintenance is required after installation. Therefore, the residual value of the material at the end of the working life of the building should also be taken into account in the costings.

Centre Culturel Alb'Oru, Bastia, France
Architect: DDA Devaux & Devaux
Photo © Joan Bracco

The copper alloy solution offers the further advantage of not requiring any maintenance, it does not corrode, even when located in a marine environment.

As a consequence of the increasingly higher maintenance costs of buildings, on the long run it is more economic to work with materials and structures that don't require much maintenance and which are long-lasting. Copper definitely belongs to this category.

Service life aspects, e.g. the need for repair and maintenance, are also linked with the quality of the work done on constructing the building. If a first-class metal is used, highly-skilled sheet-metal workers should also be used in order to guarantee a reliable installation.

Copper's longevity is due to a complex patination process. When exposed to the elements, copper develops a protective and sound patina over time with self-healing properties. This ensures extreme durability and resistance to corrosion in virtually any atmospheric conditions and, unlike some other architectural metals, copper does not suffer from underside corrosion. Consequently, it is invariably the supporting substrates or structure which eventually could fail rather than the copper itself. Indeed, copper roofs have been known to perform well for over 700 years.

"Copper leaves plenty of opportunities for creativity and is known for its exclusivity and uniqueness of realised projects."

The resistance of copper exposed to atmosphere has been measured under the supervision of the American Society for Testing and Materials (ASTM): tests have been carried out to evaluate the effectiveness of passivation, by measuring the thickness loss of sheets exposed for 20 years to different atmospheres. The results show an average yearly loss of 1 µm (one thousandth of millimetre), with the thickness loss decreasing with patination increasing.

The lifespan of copper roofing and cladding can therefore be regarded conservatively as 200 years, subject to substrate and structure – and this is endorsed by experience. Naturally, this has a significant effect upon comparative whole of life assessments in terms of energy consumption, CO_2 generation and cost.

In addition, copper is 100% recyclable, without losing its original properties or performance. If demolition or renovation is needed, it can be recovered, saving natural resources and energy, while maintaining its value.

Museum of the History of Polish Jews, Warsaw, Poland
Architect: Lahdelma & Mahlamaki Oy
Photo © Michał Łagoda

Copper is a material favoured by architects for its aesthetics as well as its durability, a life time in excess of 100 years.

Thickness loss of copper (Cu 99,9%) in 20 years (micrometre/year)	
Marine atmosphere	0,56 - 1,27
Industrial atmosphere	1,40
Industrial-marine atmosphere	1,38
Rural atmosphere	0,13 - 0,43

COMPATIBILITY OF COPPER WITH OTHER BUILDING MATERIALS

Corrosion in metallic materials on the outside of buildings can be caused for two reasons. The first is of a strictly galvanic type, i.e., when two different metals are in direct contact. The other is caused by runoff from one metal surface onto another metal surface.

Due to its placement on the positive side of the electrochemical series, copper is not negatively affected by other metals. However, if wrongly combined, other metals like zinc, aluminium and steel could be affected by copper. Therefore, building structures should be designed in such a way as to avoid contact – both direct and indirect – between these metals.

The combination of copper with stainless steel is harmless under most circumstances. Care should be taken in detailing any steel above copper as ‚rust' marks can appear on the copper caused by iron rust drips from the steel.

A combination of copper and aluminium is only possible when the aluminium has an electrically non-conductive surface, after coating or anodising. In this way, copper-bearing runoff cannot form an electrochemical reaction with the aluminium. Direct contact between the metals should be prevented by inserting an intermediate layer of non-conductive material or by simply leaving a gap.

Arrangement of copper above zinc or galvanised steel should be avoided, because the copper ions washed away in the rainwater which then drains onto the zinc react with it, resulting in accelerated corrosion of the zinc. The opposite arrangement, of zinc above copper, is harmless. However, no direct contact points between the metals must exist.

It should also be noted that rainwater running off bitumen exposed to the sun can cause corrosion problems for various materials – including copper – and certain residues washed out of concrete or mortar can cause copper to take on a blue-green colour, so it is worth preventing. Also, the wash-off from red cedar shingles can cause metals to corrode.

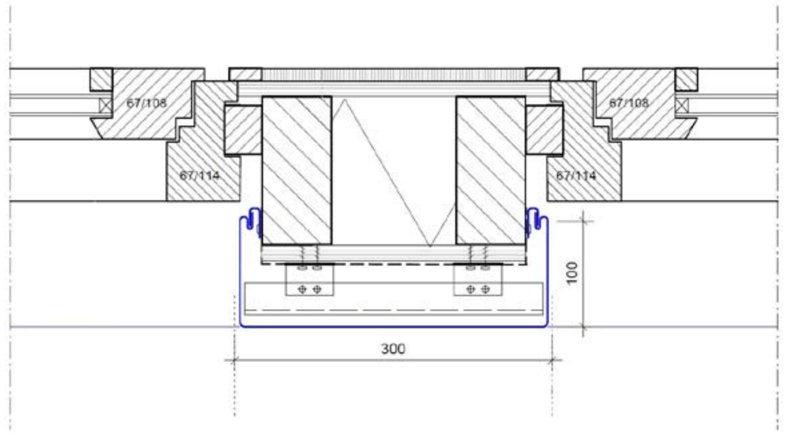
WINDOWS PLACEMENT IN A COPPER FACADE

Window types such as wooden windows, copper-clad wooden windows, bronze framed and plastic windows do not normally generate corrosion. There are a number of window manufacturers that are specialists in delivering copper-clad wooden windows. Here, there are many possibilities for design effects with the aid of different profile solutions.

Anodized aluminium windows and windows of lacquered aluminium can also be used. It is, however, important to avoid direct contact with the copper surfaces and make sure that runoff from the copper surfaces will not run onto the aluminium surfaces. To eliminate the runoff effect, the windows can be placed deep into the facade or alternatively protruding with an outside window flashing. It should be noted that cut aluminium profiles often have an untreated surface where the cut has been made. These surfaces will have to be treated to give a lasting corrosion protection.

Many effective runoff solutions can be reached with the aid of different types of joints and drop aprons. It is usually not the heavy runoffs that create corrosive problems; the ion level in those is often low as it is being diluted in large quantities of water. Dew and small quantities of rain, on the other hand, often mean aggressive water runoff.

H01



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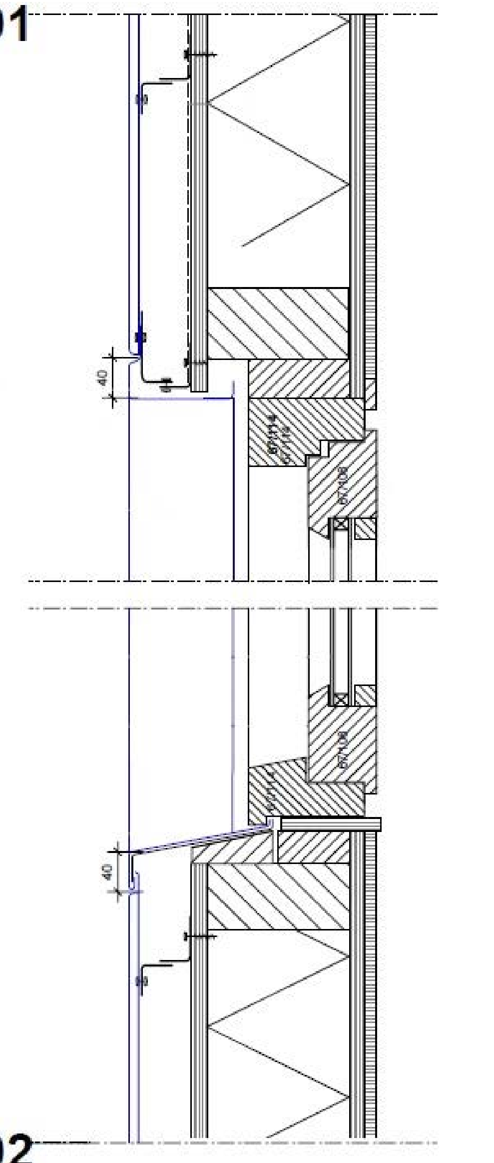


V02

Residential house, Amsterdam,
The Netherlands
Architect: Hund Falk Architecten
Photo © Ivan Brodey

A flat wall completely covered with double-sided preoxidised copper tape and flat black aluminum frames provide an abstract view of the former buildings.

ARCHITECTURAL QUALITIES

COLOUR AND PATINA

When exposed to the atmosphere, the appearance of copper surface evolves through several phases from installation to the natural development of patina – this is a unique characteristic of copper. A full understanding of this process is important for building designers.

Immediately after installation, oxidation starts on copper surface exposed to natural weathering, the influence of which becomes visible very soon. Gradually, the surface turns matt and the material develops a protective oxide layer, changing its colour to russet brown. As weathering progresses over a number of years, the surface increasingly darkens to a chocolate brown.

Continued weathering can then result in development of the distinctive green patina – green-blue in marine environment. The patina layer provides impressive protection against corrosion and can repair itself if damaged, defining the exceptional longevity of copper cladding.

A certain amount of rainwater is necessary to form the green patina and its rate of development will depend on the water „dwell time" on a surface. As a result, the process takes much longer for vertical surfaces than exposed roofs, due to rapid runoff. In coastal areas vertical surfaces patinate quite readily.

SURFACE EVOLUTION ON COPPER CONCEPT

Once in place, copper products come to life and become more beautiful over time. To discover more project examples and information on surface evolution over time go to copperconcept.org/en/references and turn on "surface evolution" filter or scan QR code.

A brochure on this topic is also available at copperconcept.org/en/publications

Airborne pollution also increases the rate of patination, which therefore takes longer in cleaner environments than in cities or industrial areas. The complex combination of factors determines the nature and speed of development of patination, giving copper unique, living visual characteristics developing over time in response to local conditions.

Many architects and owners want to see the dark brown colour or the distinctive green patina right from the moment of installation, without waiting several years or decades for the gradual changes caused by natural weathering – even in situations such as vertical cladding and sheltered surfaces where rainwater driven patination might never occur.

Different surface treatments are now available which create very similar processes to those taking place over time in the environment and the leading manufacturers are able to provide oxidation and patination straightaway.

Pre-oxidised copper offers the aesthetic appearance of an attractive, naturally oxidised surface immediately. In addition, it minimises any surface markings which might occur on bright mill finish copper and can advance the natural patination process through the effects of sun, rain, snow and wind.

Pre-patinated copper is, of course, useful in the field of historic building preservation. But its potential is most exciting when considered as a completely modern building material, combining the distinctive green colour with the freedom of form available with copper. After installation, the surface continues to develop in a completely natural manner being characteristic of copper.

PROBABLE TIME-PERIOD OF GREEN PATINA FORMATION	
In rural or upland environment	Min. 30-40 years
In city or town environment	15 to 30 years
In coastal or industrial environment	8 to 20 years

Meripaviljonki (Sea Pavilion), Helsinki, Finland
Architect: Arkkitehtitoimisto Freese Oy
Photo © Esko Tuomisto

The choice of copper recognises the material's sustainability credentials, long-life, minimal maintenance and beautiful patination. Photos taken 2014 and 2016 (weathered).

COPPER ALLOYS USED FOR ARCHITECTURE

There are more than 400 copper alloys, each with a unique combination of properties, to suit many different applications. Some of them – bronze, brass and golden alloy – are used in architecture, for roofing and cladding, thanks to several concomitant factors such as extreme durability, singular beauty and mechanical resistance.

These copper alloys used in rchitecture also display individual characteristics as they weather naturally to exteriors. They are installed especially in facades, but they can be exploited for roofs as well. In addition, their colours can be slightly modified, for example by applying a wax, in order to provide appealing nuances to the surface.

BRONZE

An alloy of copper and tin and a synonym for metallic artworks. While artists have long made use of bronze, architects are now able to make optimum use of this material. It is also well known in technology, especially where high resistance to wear is required (such as springs, gears and bearings).

In architecture, bronze is appreciated for its rigidity, resistance to wear, long lasting and resistance to corrosion. Its reddish-brown surface, when exposed to the atmosphere, gradually changes to dark brown anthracite in a manner characteristic for bronze through the effects of weathering. The patina coating forms much more slowly than with pure copper.

BRONZE
Garden Museum, London, UK
Architect: Dow Jones Architects
Photo © David Grandorge

The pavilions are clad in bespoke bronze shingles set out to reflect the scale-like quality of the bark of the surrounding plane trees.

GOLDEN ALLOY
Courthouse, St. Pölten, Austria
Architect: Christian Kronaus
Photo © Thomas Ott

Through the inherent richness of the material, the building gets a pleasant and warm character that varies continuously, depending on changing light conditions over time.

GOLDEN ALLOY

This is an alloy of copper with aluminium and zinc that shows an excellent corrosion resistance and very high mechanical properties (strength and wear resistance), due to the formation of a thin, hard, protective oxide layer containing all three alloy elements. For these reasons, it is also used in coins – the 10, 20 and 50 euro cents are made of CuAl5Zn5Sn1.

Aesthetically, it has an outstanding golden colour, with very little tarnishing over time, developing an elegant and long-lasting, matt gold coloured appearance.

BRASS

An alloy of copper and zinc with a distinctive golden yellow colour. The presence of zinc improves the mechanical strength and the hardness. Thanks to this improved strength, brass sheets used in architecture can support better their own weight as well as withstand unexpected impacts.

When exposed to the atmosphere, the original surface tarnishes and gradually turns into dark brown. Ultimately, it may develop a patina but much slower than copper. In addition, brass is really well-suited for interiors and its surface can be treated to provide a brownish finish.

BRASS
Ferry Terminal, Stockholm, Sweden
Architect: Marge Arkitekter
Photo © Johan Fowelin

Roofs and walls are clad with burnished brass, which harmonises well with the stone and stucco facades in the background and creates a unified, sculptural expression. In addition, variations in surface texture are achieved using different techniques.

STRUCTURE AND INSTALLATION

ROOFING SYSTEMS

The structural formation of metal-plate claddings has been refined in the past centuries on the basis of characteristics of the material. Cladding metals are used in manufactured forms that are thin (0.5-1.5 mm), but have large surface. It is a consequence also of this fact, that the dimension of these plates change significantly on the influence of heat, and as roofing materials, they are frequently exposed to even 100°C difference of temperature.

The roofing must accommodate the dimensional changes caused by thermal expansion and at the same time it must fully satisfy requirements for roof membranes, i.e. they must be waterproof, frost-resisting, durable and strong.

Sheet metals used for roofing – and copper is outstanding among them – are easily formable and leakproof. The dimensions of trays must be selected and joints formed in ways that they must be able to tolerate thermal movement while preventing the infiltration of moisture along these joints.

It is a basic principle in case of any type of roofing that metal cladding sheets are never fixed in a non-removable way directly onto the substrate. Meeting sheets are adjoined by multiple splicing (seam) to each other and are fastened to the surface to be covered onto fixed retainers (cleats, lock strips) after folding.

Through this solution, expansion gaps are formed and trays are able to tolerate dimensional changes caused by the influence of heat without visible deformation, corrugation or other damage.

In practice, two types of roofing are common: standing seam roofing and batten seam (or batten roll) roofing.

Standing seam roofing is made up of trays arranged square to the cornice (i.e. parallel to the slope line) and are connected to each other with double standing seams. It is applicable for slopes above 3 degrees.

Generally, cleats are used for fastening copper to the substrate, with copper nails where two neighbouring trays meet. Cleats are folded together with trays to create the seams. Trays are fixed this way, but being an indirect fastening method, the joint allows some movement.

When laying trays, workers must leave gaps of a few millimetres to enable them to accept transversal thermal movement.

The usage of sliding cleats is a specialty of copper cladding. These consist of two parts capable of moving off from each other and allow an even greater thermal motion.

For continuous fastening along a line, lock strips are used, which are fixed directly to the substrate on the whole length or spaced continually, and the sheets are folded on and hooked in them.

Batten seam roofing, similar to standing seam roofing, is built up from strips, but these are not fastened directly to each other, but to battens nailed or screwed on the substrate parallel to the slope line. U-shaped cleats are put under the battens. The whole batten is then covered with batten cladding sheet with drip bordering.

This solution is more impervious than standing seams, because joints are positioned higher. It can be used even in case of 3% slope of a roof.

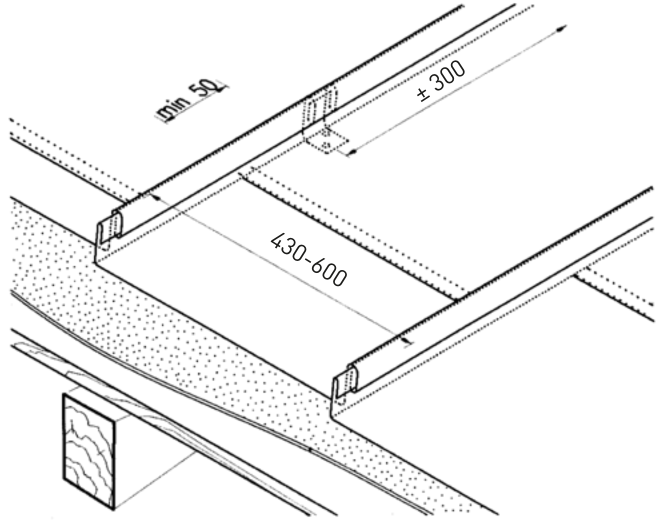
Both can be made from trays assembled from sheet or strip cut to the length of the rafter or from prefabricated, profiled strip elements.

Montevergine Sanctuary, Mercogliano, Avellino, Italy
Architect: Studio Arch Luigi Picone

The machine-rolled copper sheets have been installed onto supporting wooden boards as double standing seam system.

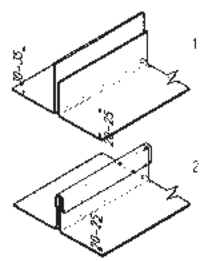
Sport and Leisure Centre, Budapest, Hungary
Architect: T2.a Architects
Photo © Zsolt Batár

A major sports building mutates its straightforward rectangular plan into a complex faceted copper roofspace.

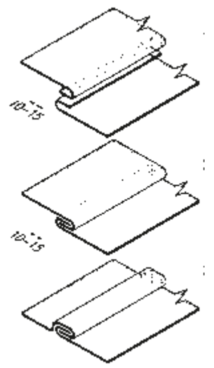


GENERAL SCHEME OF STANDING SEAM ROOFING

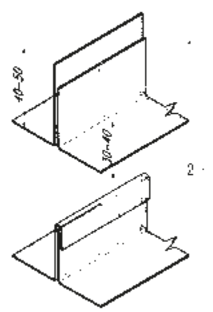
MAKING OF A SINGLE LOCK STANDING SEAM

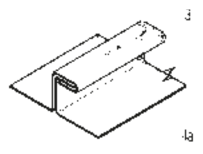


FLAT LOCK SEAM

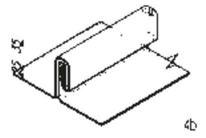


MAKING OF DOUBLE LOCK TYPES OF SEAMS

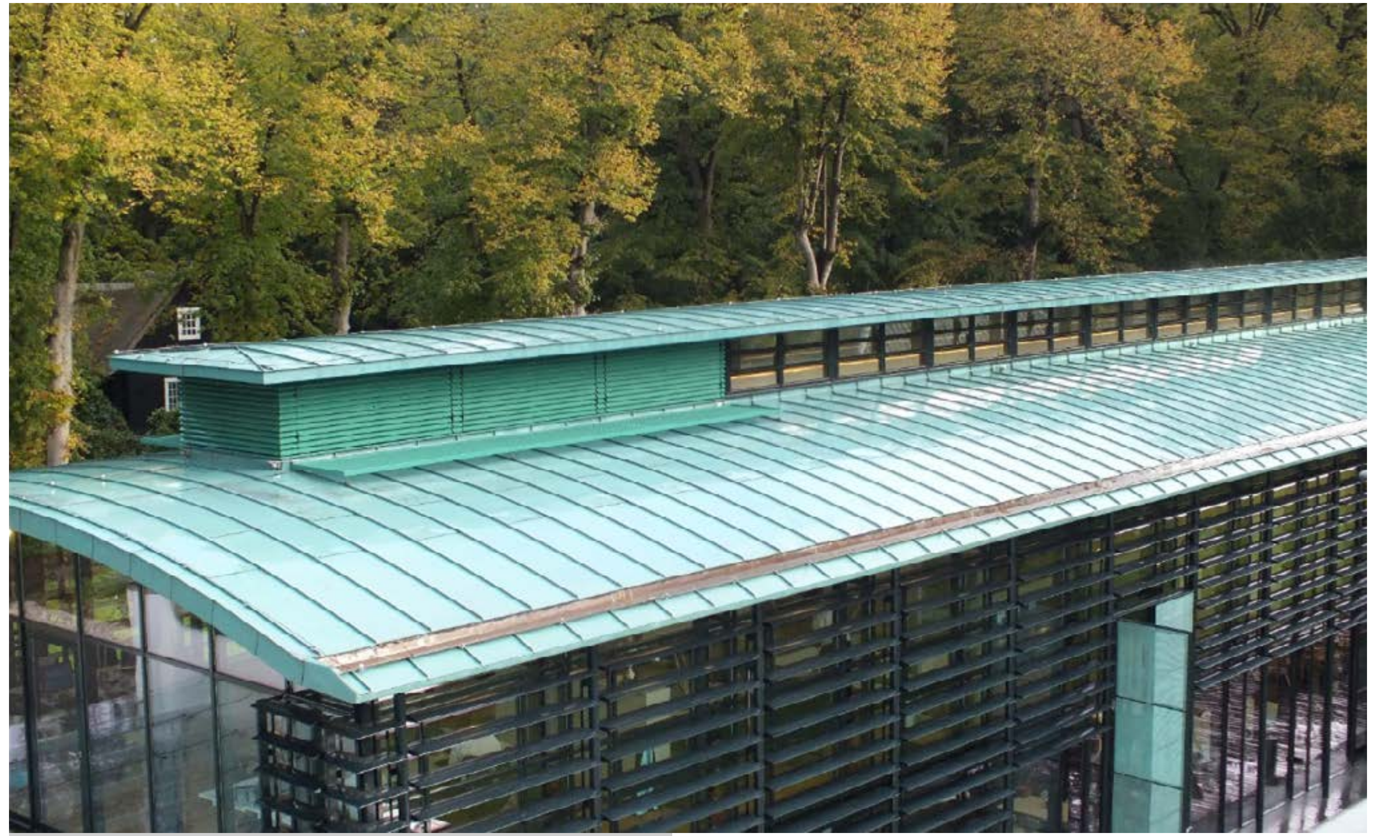




ANGLE STANDING SEAM



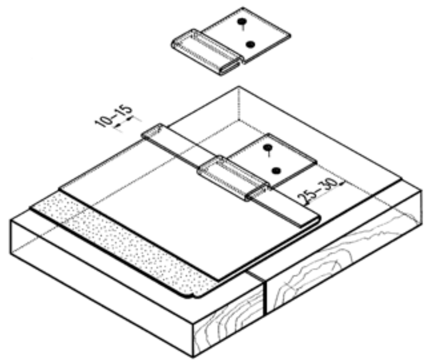
DOUBLE LOCK STANDING SEAM



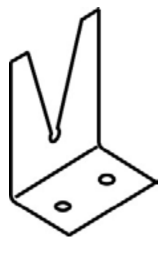
The Orangery, Huizen, Netherlands
Architect: Braaksma & Roos Architectural Office
Photo © ECI

The entire roof is covered in prepatinated copper, same as the bays of the Mansion. Pre-patinated copper perforated screens are used in front of doors and on east elevation.

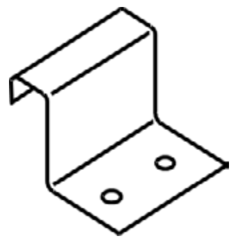
HOOKING CLEAT



FIXED CLIPS

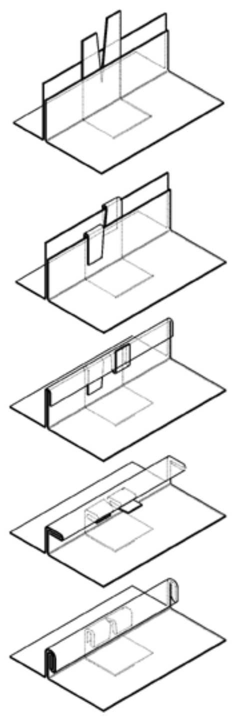


FISHTAIL CLIP



PROFILED FIX CLIP

DOUBLE LOCK STANDIG SEAM WITH FIXED FISHTAIL CLIP



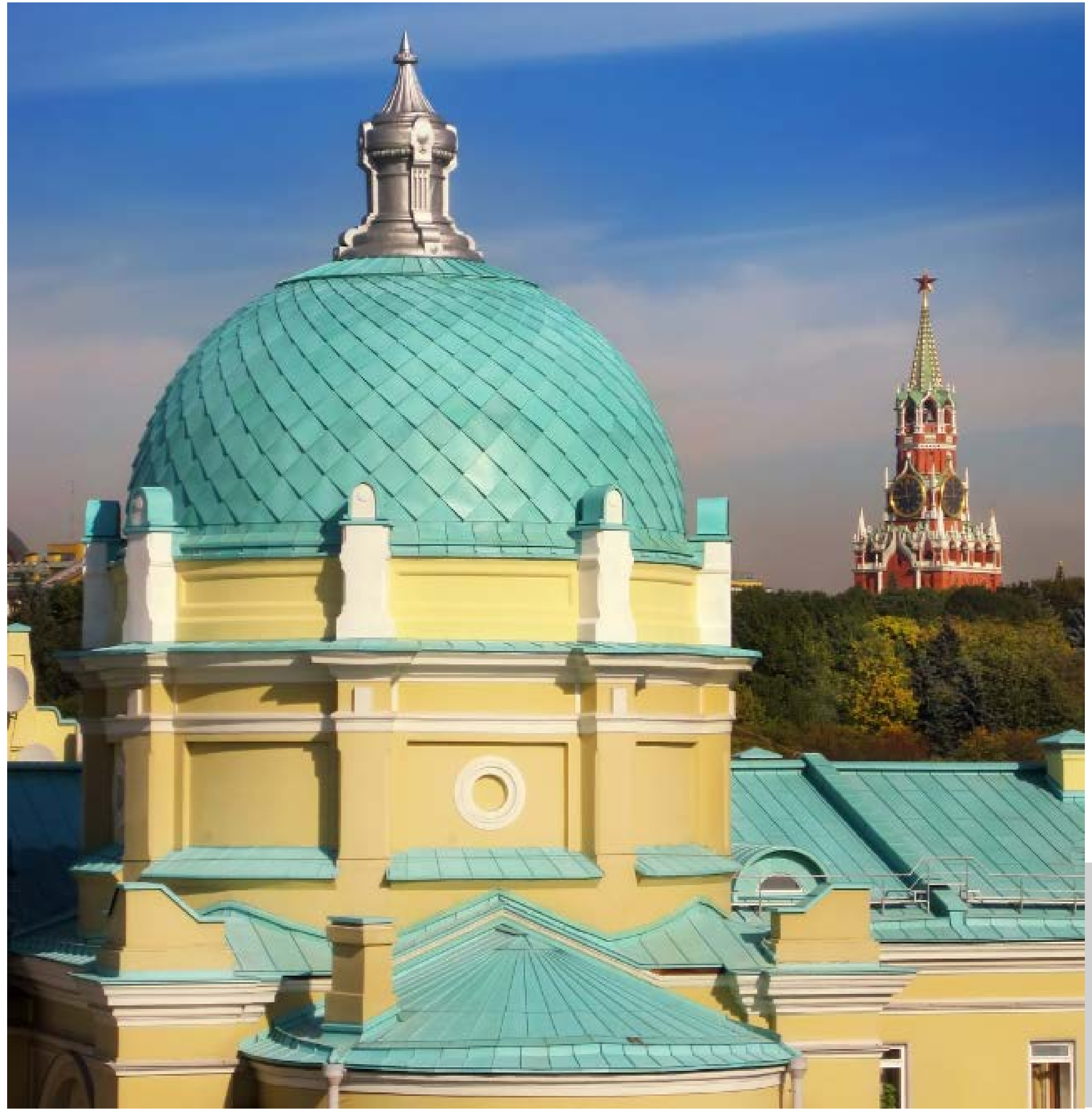
Another type of roofing is where prefabricated profiled sheets are used, which is akin to fluted sheets made of any other metals. It is assembled from corrugated panels fitted with retainers. The system allows very quick work on large plane surfaces in the frame of a previously worked out system. The result resembles batten seam roofing.

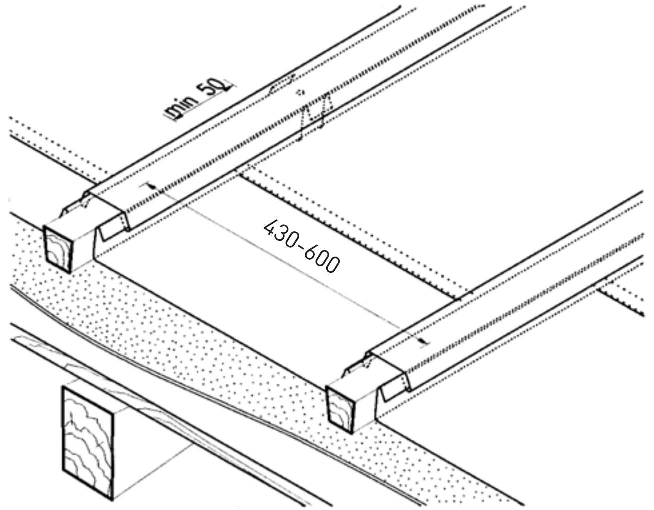
The roofing system chosen – beyond any aesthetic regards – must be decided by the basic geometry, the slope of roof is a determining factor.

Batten seam roofing or the application of profiled sheets give a sharp-featured image by making large plane surfaces lively. But they are not applicable on arched surfaces or on more complex roof forms; what is more, the installation of batten seam roofing is rather labour-intensive.

Highly complicated roof forms can be relatively easily covered with standing seam roofing. The result will show a homogenous picture, where trays are less accentuated. The width of trays and the thickness of sheets are determined by aesthetic considerations and by the dimensions and relations of the roof, the location of roof superstructures and – last but not least – the wind force affecting the roof.

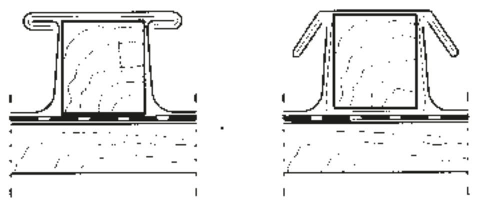
When selecting a roofing system, the designer must consider the reliability of the structure, its feasibility, etc., taking stock of all architectural and aesthetic requirements.





GENERAL SCHEME OF BATTEN SEAM ROOFING

INSTALLATION OF BATTEN SEAM ROOFING



STYLE A

STYLE B

Rosneft Copper Roof, Moscow, Russia
Architect: Archexpert
Photo © Savros

Unique three-dimensional copper shingles for a stronger structural effect crafted with self-built machines by a local specialist.

Le Safran festival hall, Brie Comte Robert, France
Architect: S.C.P.A. Sémon-Rapaport
Mandataire de L'Equipe, Brie Comte Robert
DUPRE, Saintes
Photo © KME

Copper sheet has been used for roofing for centuries; this includes copper shingles (or rhombuses), small-sized metal sheets which have been used for the roofing of domes, facades and other roof areas.

A varied-texture surface can be installed with overlapping scales or shingles, which use the characteristics of the metal. It comprises uniform elements sold by the factory or made on-site. In its size and texture it resembles small-tile slating, but its structure is different. Diamond, rectangle or square trays are folded on their four edges in a way that single lock seam joints overlay and are hooked into each other on all sides. The elements are fastened with cleats, one by one. Because their small size and seamed edges make them rather rigid, the whole covering can be fastened to a batten frame following the distance of retainers.

FAÇADE AND WALL CLADDING

With the twentieth century came a transformation from copper's historic role as a durable roofing material to a flexible architectural skin over any surfaces, including walls.

Copper can provide a complete external skin, wrapping around complex building forms with material continuity. Surfaces can be flat, curved or faceted and used at any inclination or pitch, and in any environment. Alternatively, it can give distinctive character to individual façade elements, particularly when used in conjunction with other high-quality materials such as stone, brick, glass and wood.

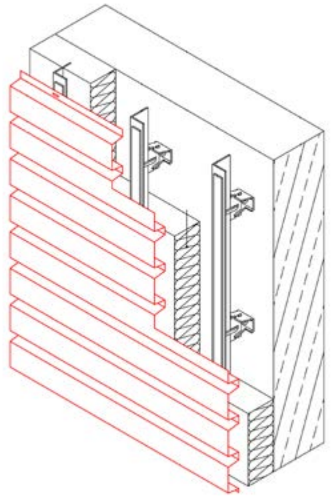
Apart from standard copper sheet, there are other copper products that create extra dimensions of modulation, texture and transparency for architectural surfaces. Installation techniques and systems also help to define architectural character – there is an extensive range of factory pre-fabricated systems for facades, as well as copper sheets and strips.

The cladding construction presented here follows the concept of a bracket mounted, ventilated cladding, creating an optimised system that securely envelops the closed, wind-tight inner construction. A ventilation area is generally required for several reasons: to reduce humidity, to allow penetrating rainwater to diffuse out of the construction, to create a capillary separation between the cladding and the breathable thermal insulation or support structure and to diffuse condensation on the underside of the cladding.

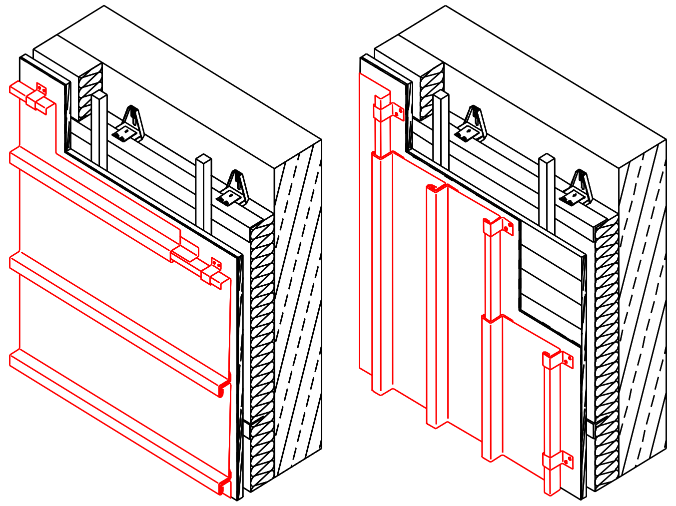
FACADE SYSTEMS

STANDING SEAM AND PROFILED SHEETS

Copper sheets can be installed in facades with the same seaming techniques used for roofing – in most cases angle standing seam is acceptable as water tightness is not a major concern on vertical surfaces. In addition, it is possible to use various types of profiled sheets (sinusoidal wave, trapezoid), including custom-made profiles.



PROFILED SHEET



ANGLE STANDING SEAM CLADDING

Kunstmuseum, Ahrenshoop, Germany
Architect: Staab Architekten
Photo © Christian Richters/ KME/ MN

The apparently random, animated profiled surface structure flows continuously with no visible offset giving the impression that the whole has been cast as one piece.

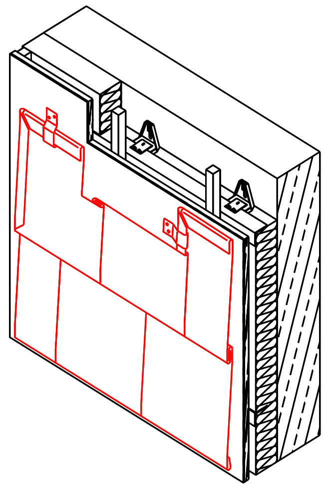
Museum of Fire, Zory, Poland
Architect: OVO Grąbczewscy Architekci
Photo © Tomasz Zakrzewski / archifolio

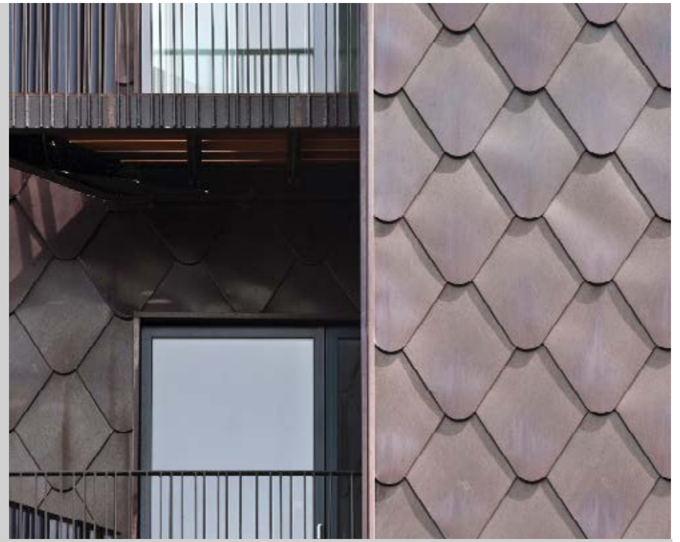
This unusual building, the Museum of Fire, resembles a flame creeping along the ground - Like fire dancing on the ground.

SHINGLES

Shingles offer a distinctive „fish scale" appearance with shapes including squares, diamonds, rhomboids and rectangles. These flat tiles are laid simply by hanging them and interlocking them with each other, offering a relevant economic advantage.

Shingles have a 180° folding on all borders – two sides are provided with a fold coming forward or with a downstand. All folds and notches are pre-processed in the factory. This ensures that the corners of buildings and connections to other constructional elements such as windows and doors are completely weatherproof.





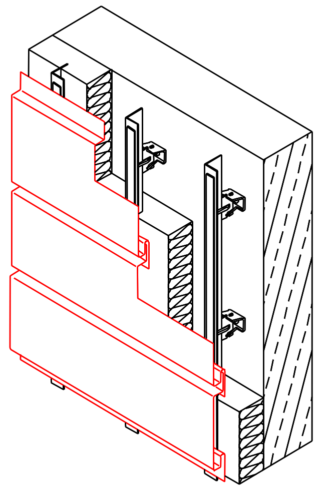
Field Street/Leeke Street, London, UK
Architect: Project Orange

The external façade is clad in oxidised copper 'scales' that overlap and soften the dominant geometry of the building.

PANELS

Panels are cladding elements pre-formed on two sides that can be assembled vertically, horizontally or diagonally to give a linear, striated appearance. Assembly at the building site is performed according to the tongue and groove principle or by overlapping. Individual lengths are as long as 4,000 mm with a width of up to approx. 500 mm.

As panels are not laid in contact with the underlying structure, it is necessary to put a solid material (wood, plastic) between the copper and the structure, especially at ground level up to approx. 2 m, in order to avoid signs and dents due to possible shocks.



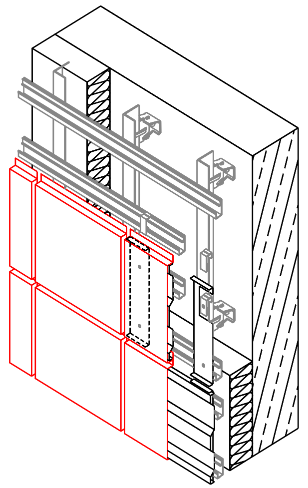
Special Education School in Dinkelscherben, Germany
Architect: Frech & Mair Architekten BDA, Augsburg
Photo: KME

Horizontal installed panels with visual gap give a specific architectural character of facades.

CASSETTES

Cassettes are cladding elements with folded edges on all four sides available in a range of rectangular proportions. They are produced project-wise according to the specific design concept. Cassette cladding is suited for larger flat areas, offering great flexibility in terms of formats, the layout of joints and fixing principles.

Fixing is usually achieved by riveting, screwing, hidden/subsurface fittings or by means of bolt hooks to fix the cassettes directly to the substrate.



Clarion Hotel Post, Gothenburg, Sweden
Architect: Semrén & Månsson
Photo © Lennart Hyse

This was made up of copper in three strip heights – 200, 250 and 300 mm – and three different intensities of pre-patinated copper, by varying the amount of green over the dark brown background.

TRANSPARENT STRUCTURES

The copper industry is continuously developing new products in order to enhance the aesthetic merits of copper and copper alloys used in architecture, as well as to expand the freedom that architects can enjoy by working with copper.

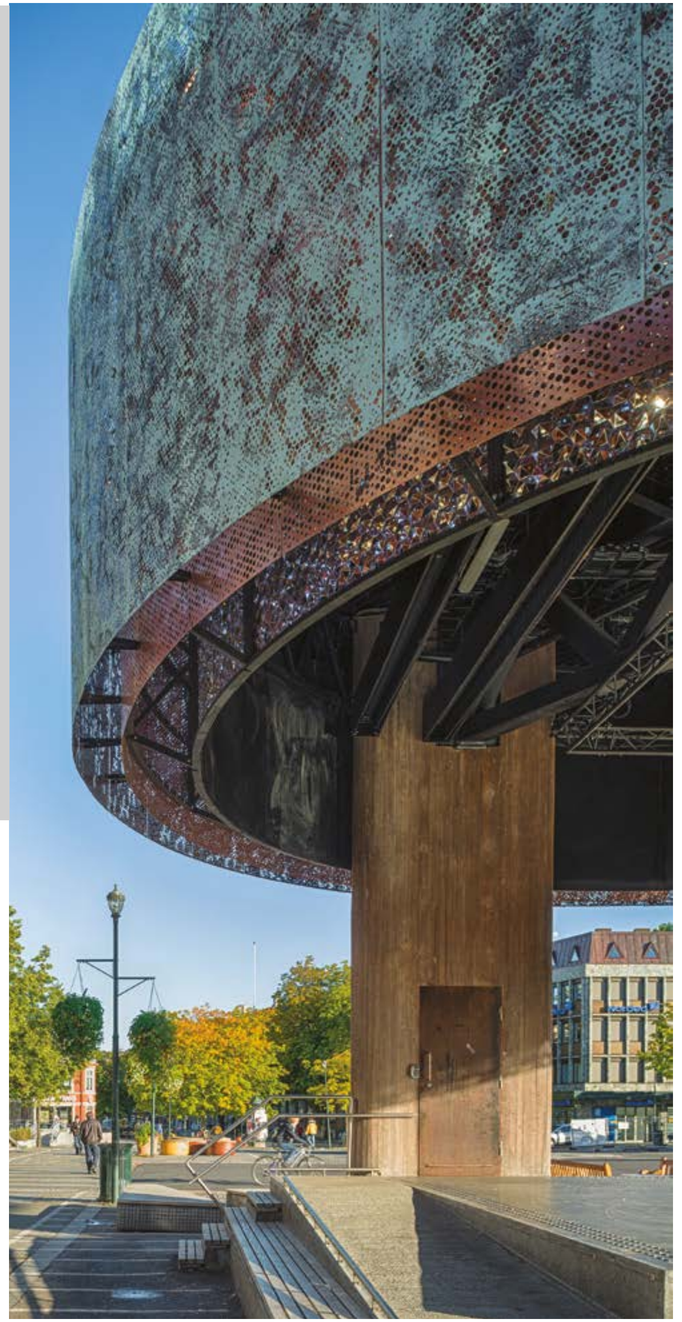
One of the latest products are the perforated and expanded copper sheets and strips which add new possibilities for transparency and can be individually manufactured to the vision of the architect.

Perforations on copper sheets and strips offer many possibilities for singular design, including subtle patterns, images and even text. Many different levels of transparency can be created – from almost complete transparency to a subdued translucence.

The effect of back-lit facades can be designed very individually by using a large number of different perforation patterns. There are also virtually no limits to the use of perforated copper and copper alloys as decorative indoor elements.

Communal Stage, Trondheim, Norway
Architect: HUS arkitekter AS
Photo © Mathias Herzog

Daylight plays on its hand-patinated multi-layered surface adding richness to this floating canopy, then at night it becomes luminescent in its own right.



Expanded mesh structures are made by perforating and then stretching the material to create a metal curtain with functional aesthetic qualities. The many different structures of the copper rib mesh provide openness and create a solid barrier, offering both transparency and mechanical protection.

On the building, the use of copper mesh designs brings a pleasant lightness to the façade. When installed in front of glass areas, they offer security in an aesthetic form as well as fascinating impressions from inside and outside.

Centre Culturel Alb'Oru, Bastia, France
Architect: DDA Devaux & Devaux Architectes
Photo © Joan Bracco

The transparent copper alloy mesh facades encase open circulation routes around three sides of the building, generating external spaces for reading and enjoying the views. At night, the building becomes a glowing beacon with internal lighting shining out.

DYNAMIC FACADES

The building facade has to protect the building and to act as its face to the outside world. It must have a durable, weatherproof sealing layer – a surface which protects it against the wind and weather and is simple to maintain. In addition, the outermost layer of the facade must be combined with an effective, functional insulating material.

But in the last few years, another function has been added to the well-known aesthetic, weatherproof and insulating facades' functions – the optimization of energy consumption. Either through passive shading and ventilation or through complex systems, the building skin transforms dynamically to regulate the internal environment in order to reduce its energy demands.

Of course, copper has a prominent role to play in dynamic facades. Durable, malleable and scalable, it is a material of choice for architects who innovate in designing functional cladding. In the form of copper sails or strips, they are able to better manage light and heat, and improve the energy performance of buildings. In the form of a raw surface that evolves over time, the façade gives life to a building and becomes the key to its environmental integration.

Merchant's house, Copenhagen, Denmark
Architect: HUS arkitekter AS
Photo © Jens Markus Lindhe

Areas of the copper curtain can simply fold up to generate a pattern of fenestration matching that of the adjacent buildings. When closed, the curtain becomes homogenous and impenetrable - but then dissolves to reveal the interior with lighting at night.

DYNAMIC FACADE

DYNAMIC FACADES ON COPPER CONCEPT

To discover more project examples and information on dynamic facades go to copperconcept.org/en/references and turn on "dynamic facade" filter or scan QR code.

Responding to changes in urban life—both organisational, technological and societal—architects and town planners must innovate. Dynamic copper façades enable modern buildings to interact with their environment, and can limit the use of artificial lighting and heating, regulate aeration, light or transparency, and create unprecedented visual effects.

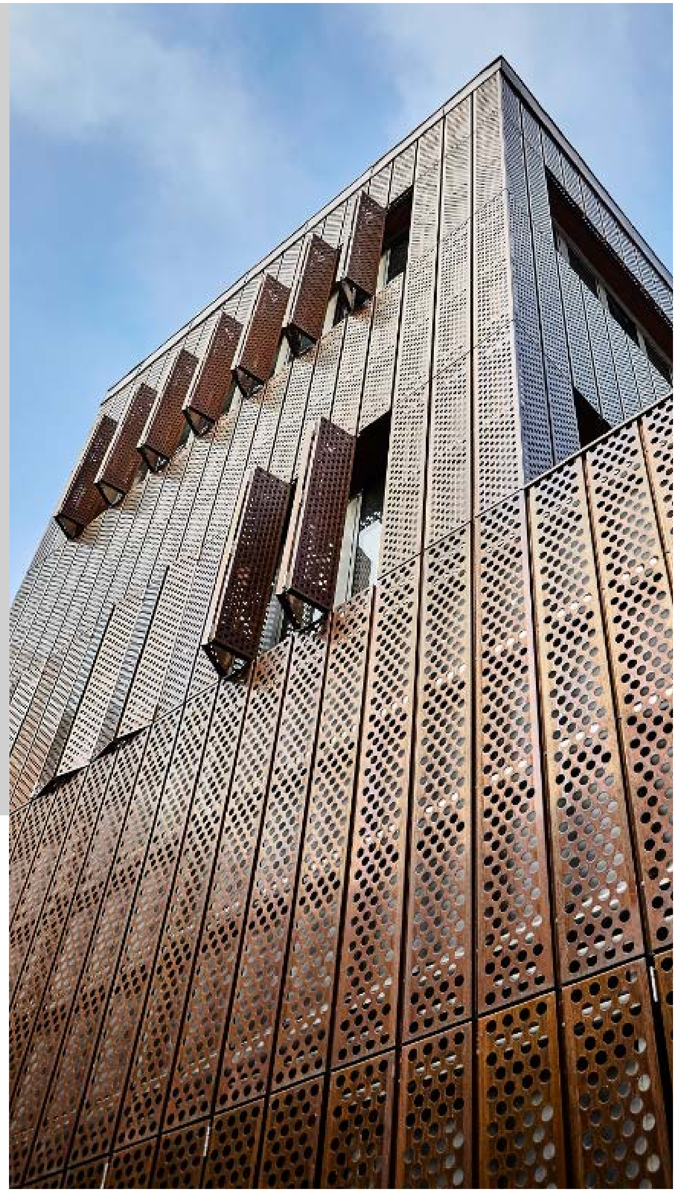
Conservatoire Claude Debussy, Paris, France
Architect: BasaltArchitecture architectes
Photo © Sergio Grazzia

A skin perforated by the beat of the melody that emerges and takes shape in the outer walls.

La Monnaie de Paris (Paris Mint), France
Architect: AAPP / Philippe Prost
Photo © Benjamin Chelly and Aitor Ortiz

Creating an architecture where the chosen materials evoke the expertise of the practitioners working inside the house.

Copper and its alloys allow great architectural creativity, and are the go-to materials for functional façades thanks to their malleability and ease of installation. Copper sheets are lightweight, easy to work and assemble, aesthetically pleasing and extremely durable without maintenance. A wide range of finishes are also available: smooth and glossy, perforated, embossed, pure or alloyed, raw or pre-patinated.

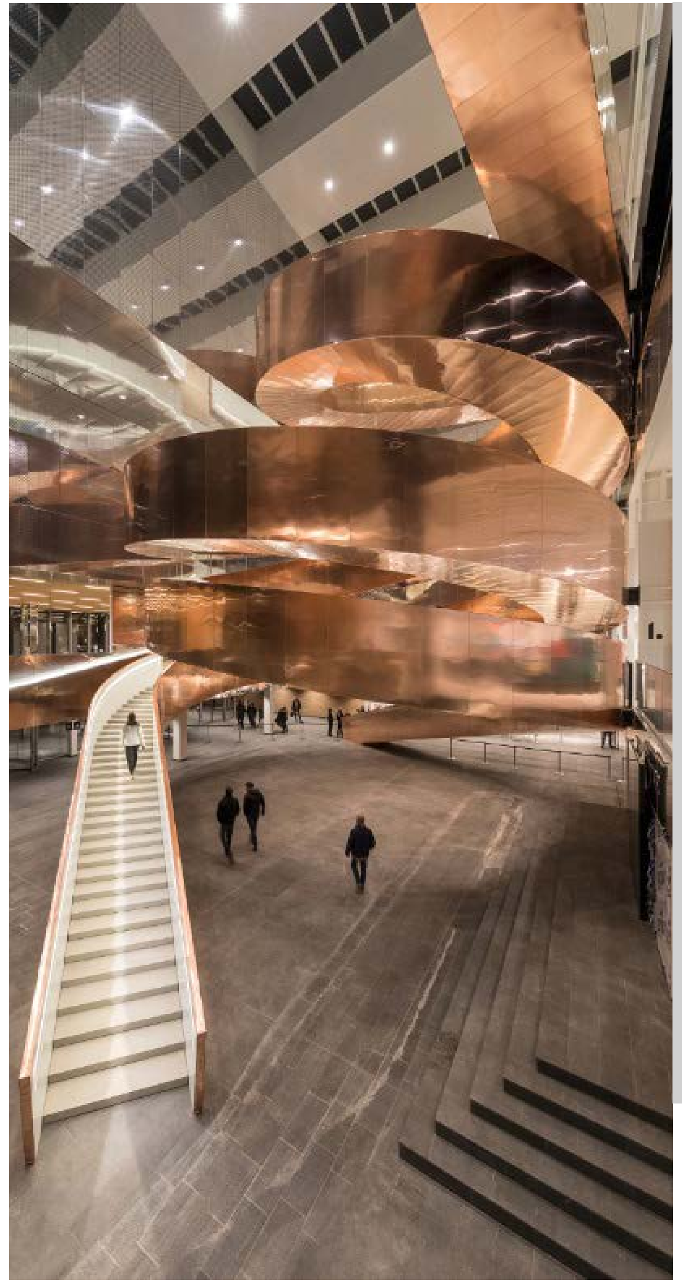


Pegasus Academy, London, UK
Architect: Hayhurst and Co.
Photo © Kilian O'Sullivan

A golden copper alloy frontage announces the entrance to this south London school – recipient of several awards, including Winner of the 2015 Architectural Review Schools Award – unifying disparate existing buildings.

DESIGN CONTINUITY

As a roofing material, copper has traditionally been used to form associated elements such as flashings, vents, gutters and downpipes. Modern design took this further with the growing use of copper for vertical cladding, rain screens and curtain walling, focusing on copper as a comprehensive skin to express building form and maintain performance and material continuity. Nowadays, architects continue to exploit this flexibility and freedom of form, with complex shapes made possible by computer-aided design techniques.



Experimentarium - The Helix Staircase, Copenhagen, Denmark
Architect: CEBRA
Photo © Adam Mørk

An entirely new architectural setting that brings science and technology into focus – from the illustration of fluid dynamics on the facades, to the spectacular Helix staircase that meets the guests as a shining icon immediately upon passing the main entrance.

DRAINAGE SYSTEMS

A complete roof drainage system is required – with correctly sized gutters and pipes – for the roof to provide effective protection against rain, snow, sleet, etc. It is no less important for the roof drainage system to be designed to withstand the weight of snow and the formation of ice.

The roof drainage system may be based on surface mounted gutters and downpipes or on recessed, built-in systems, or on a combination of these.

Gutters and downpipes made of copper must meet the demands of the European standards EN 612 and EN 1462. In particular, the standard EN 612 specifies requirements for gutters and downpipes under the usual service conditions, i.e. catching and draining away rainwater, melted snow or ice water from a building to a drainage system or a sewer outside the building.

The performance of a gutter and drainage system made with standardized products depends not only on the properties of the products, but also on the design, construction and behaviour of the relevant parts of the building.

Maintenance, durability and longevity are important factors to consider when designing gutters and downpipes. Copper is an excellent choice because of its low maintenance, high resistance to corrosion and long life. Even in severe climates such as marine atmospheres, a well-designed copper rainwater system can provide many years of low maintenance service.

The shape and dimensions of a gutter are defined by the quantity of water to be drained away from the roof to the downpipes and by architectural design requirements. The tendency of the guttering to become blocked due to the accumulation of rubbish for example, also has to be taken into account.

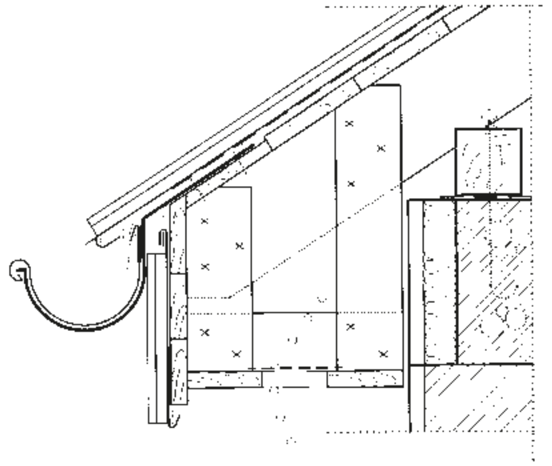
There are many different types of prefabricated system on the market, such as semi-circular and rectangular gutters, and lengths of between three and six metres are the most common. A number of bespoke systems are available as well.

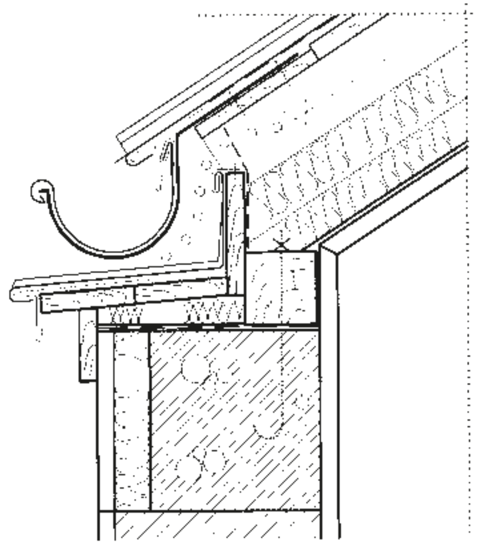
The distance between gutter hooks should not exceed 600 mm. In the case of gutters in exposed positions – where large amounts of snow could collect, for example – the gutter hooks must be fitted more closely together (400 mm, for example). The gutter must be fitted with a slope of no less than 5 mm/m in order to make the water flow away; a higher slope means a higher flow. Guttering must never be fitted with a backward slope.

A gutter is generally long and straight, so it may be necessary to use an expansion joint to allow the gutter to expand and contract.

At the lowest position of the gutter, downpipe must be connected. The location of the connection must be chosen taking into account local rules, sewage system connection, architectural features and aesthetics. Downpipes are attached using pipe union pieces, with a maximum distance of 2 m between pieces.

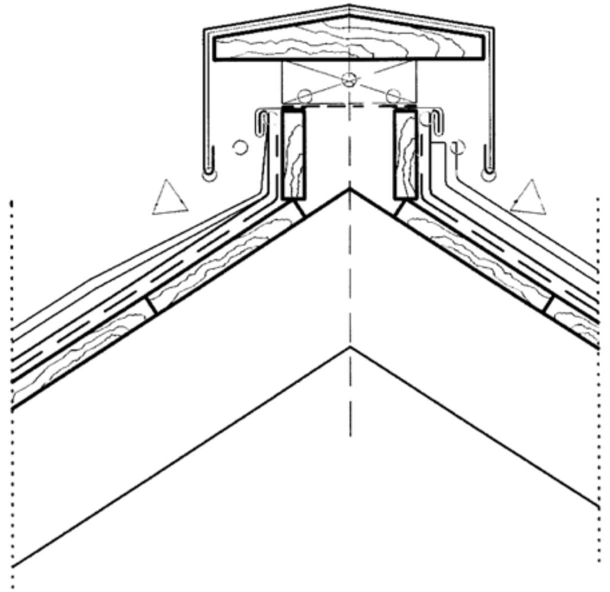
HUNG GUTTER



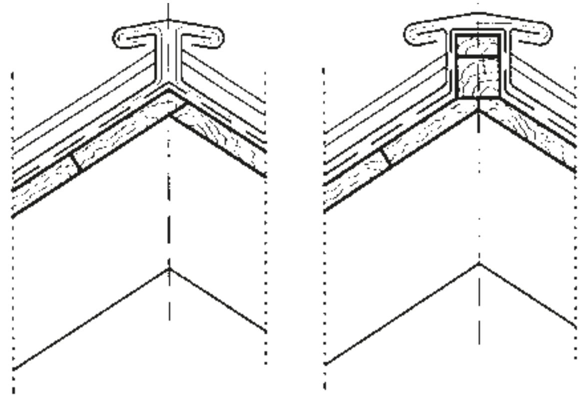


RIDGES

VENTING RIDGE



NON-VENTING RIDGE



In addition, flashings are required to prevent moisture from entering the building by diverting it. Copper is an excellent material for flashing because of its malleability, strength and high resistance to the caustic effects of mortars and hostile environments. Since flashing is expensive to replace if it fails, copper's long life is a major asset in this application.

Copper cladding offers a good basis for exterior lightning protection because the seams create a conductive covering over the entire surface. Instead of conductor tapes the metal cladding on roofs, facades and gutters may be used as conducting part of the lightning protection system. For further guidance see IEC EN 62305 and national regulations.

Copper Concept

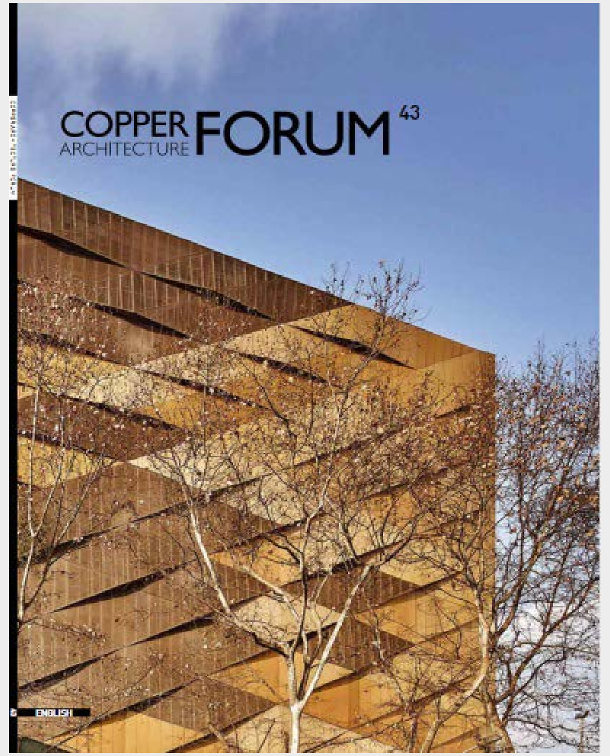
COPPERCONCEPT.ORG

The diversity of surfaces offered by copper and its alloys today is greater than ever. To see copper references in modern architecture visit copperconcept.org or scan QR code and choose your language version.

Copper Architecture Forum

COPPER ARCHITECTURE FORUM MAGAZINE

CAF magazine shows you the best examples of contemporary architecture. Order your free printed copy or read them online: copperconcept.org/en/copper-forum or scan QR code.



SUBSTRATES

It is a basic requirement that the substrate for copper sheets and strips must always be smooth, even and strong, letting nails or screws be securely fixed. The most common substrates for copper are steel trapezoidal sheet, insulated panels and wood, but other materials that meet these criteria can be used as substrates as well. It is also necessary to be sure that the substrate is compatible with copper – for example, the wood may contain fire retardant, preservatives or insect-killers.

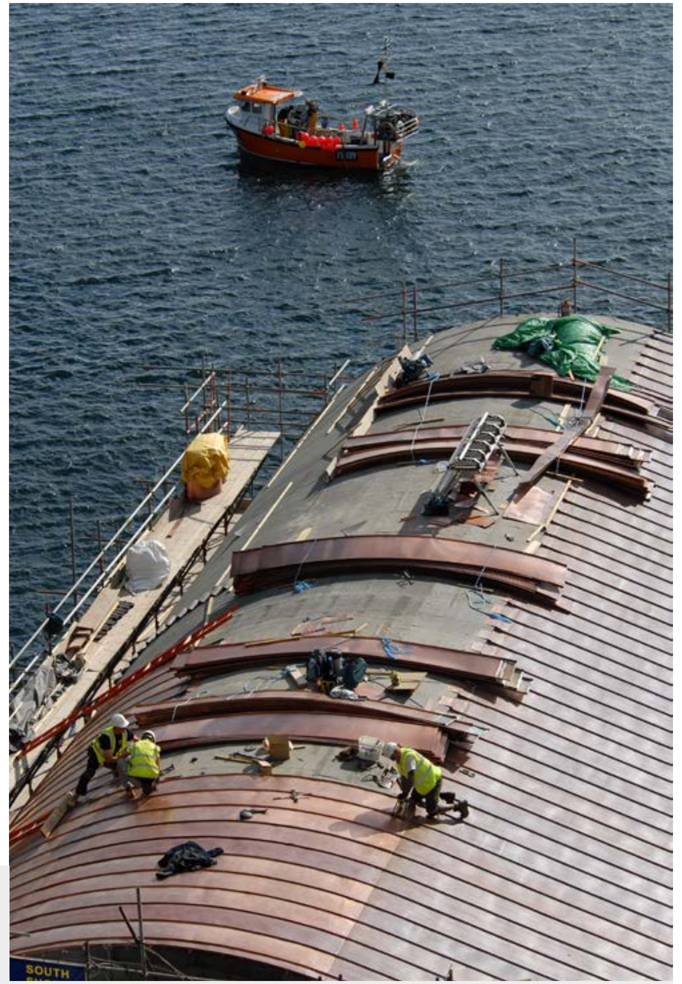
Concrete and brick structures (e.g. coping) should be covered with a proper layer in order to level their surface, as uneven areas can easily be seen in the finished covering or underlying walls, facade decorations and windows, the mortar screed is enough of a foundation. Hard mineral wool can be used under certain conditions.

With warm roof constructions, rigid insulation panels can provide a suitable substrate. However, fixing becomes more complicated. There are two basic approaches: either to provide two layers of insulation, each laid between battens, with the second laid counter-battened to the first; or to use specially extended fixing clips which pass through the depth of the insulation to an additional nailable substrate beneath. For fastening copper or copper alloy sheets to the substrate copper nails or stainless steel screws, clamps or rivets are recommended to avoid corrosion problems.

Profiled copper (as well as most types of cassettes) is more rigid than flat sheet on account of their design. This means that an absolutely flat surface is not required in respect of bearing strength. However, it is important for the substrate to be sufficiently even and flat to ensure that the surface of the sheet metal does not become uneven or dented.

Substrate and copper must be separated with a tangential separation underlay, which can allow movement in the copper sheeting, provide a temporary weathering for the building during construction, deal with irregularities on the substrate surface and absorbs sounds caused by wind or rain at a great extent.

There are several types of separation underlay. What is important: it must be durable and must ensure easy diffusion. In most circumstances, industrial felt is the preferable solution, because this material has very good tangential, noise barrier and vapour diffusing properties.



The Lizard Lifeboat Station, UK
Architect: PBWC Architects
Photo © Geoff Squibb (Cornish Pixels)

The building is predominately timber frame with glulam-curved members providing the iconic shape. The double skin roof is finished in copper trays with standing seam joints.

All Saints' Academy, Cheltenham, UK
Architect: Nicholas Hare Architects LLP
Photo © Nicholas Hare Architects LLP

The cladding of the chapel was undertaken with real craftsmanship, the copper shingles gradually reducing in size to accommodate the conical shape reaching through the atrium roof.

SUBSTRATE FOR FACADES

The seamed copper-clad wall with facade sheeting in the form of strips or sheets requires a firm substrate, as does traditional copper roof, and this substrate must be able to withstand dressing of the sheet and permit clips to be used for fixing purposes. In the case of profiled sheets, panels and cassettes, the technical requirements for the substrate are more or less the same.

Irrespective of whether the building is new or being renovated, the underlaying surface must be level. Nowadays, adjustable metal spacers are available which permit even old, uneven surfaces to be fitted simply so that they are level.

Lofts Antwerp, Belgium
Architect: Hub
Photo © Hub / Plateau Bvba

EXTERNAL CLIMATIC EFFECTS

RAIN AND SNOW

Roofs and exterior walls must not be permeable to rainwater and snow. Where hard driving rain is expected, special attention should be given to roof slopes, joints and seam details, eaves, ridges, flashings and connections to higher walls.

Taking into account that a copper cladding is "discontinuous", proper design and technical solution must be followed in order to avoid any infiltration through the sheets. Contiguous sheets must be overlapped and bent together, according to well-known techniques, like the standing seam or the batten roll. The choice of the proper joint depends also on the roof slope.

The height of the standing seam should be 25 mm at least, and the direction of the bending must take into account also the direction of the main wind. When the slope of the roof is less than 7°, sealing strips should be applied between the sheets, in order to avoid the rise of water by capillarity.

Snow on the roof can lead to load concentrations which have to be taken into consideration when designing the load bearing structure.

If the roof is to provide effective protection against rain and snow, it is also important for the roof drainage system, including gutters and piping, to be designed and dimensioned correctly. In addition, the thermal insulation of the eaves and the roof and the ventilation systems must be carefully installed in order to prevent all kinds of ice formation.

WIND

Wind loads are the strongest, most frequent hostile factors which affect roofs and facades. In areas where high winds occur, roof covering and facade cladding must be carefully designed and sheets securely fixed to the underlying structure. The density of fixing clips has to be designed according to windload distribution.

If the wind blows directly onto the building, the strongest positive pressure occurs towards the centre of the windward side. On the opposite side, the greatest negative pressure occurs at the corners and upper section of the facade. The distribution of pressure is also affected by the direction of the wind, the turbulence, the geometrical design of the building and the topography of the surrounding area.

TEMPERATURE

Roofs and facades are subject to great temperature variations, which in turn give rise to stresses and movements in the material. Primarily the roof, but also the facade, has to be designed with a view to the fact that temperature variations may occur between the external surface and the underlying structures.

Country House, Segovia, Spain
Architect: Forero Arquitectura

The location is subject to some extreme weather, sun and snow, large temperature oscillations, solar radiation and strong storms.

THERMAL MOVEMENT

Facade cladding and roof covering may be subject to great temperature fluctuations both during single 24-hour periods and over the course of a year. When designing copper structures, movement and stresses related to temperature variations must be accommodated; it is important also to take into account possible movements in the underlay.

All materials react: they either shrink or expand when the temperature changes. It is necessary to take into account the coefficient of thermal expansion of each material in order to reliably determine the degree of change. A copper sheet of 1 m has a thermal expansion of 1.7 mm with a temperature difference of 100°C.

Flat sheets can absorb thermal movement across the standing seams provided the seams are designed to accept the appropriate amount of expansion. Longitudinally, the sheet is able to move freely if it is attached using sliding clips and including a degree of movement at either or both ends. In the case of copper sheeting, a double lock welt is normally used across the width of the sheet, irrespective of the slope. Lateral movements are absorbed by the basic spacing (about 3-5 mm) which must exist between the standing seams.

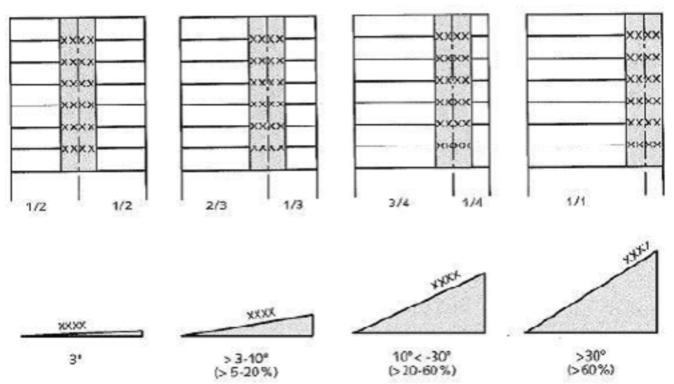
When it is necessary to use nails, installers must enlarge the hole on the sheet, in order to allow the thermal movements.

FIXED ZONES AND MOVABLE ZONES

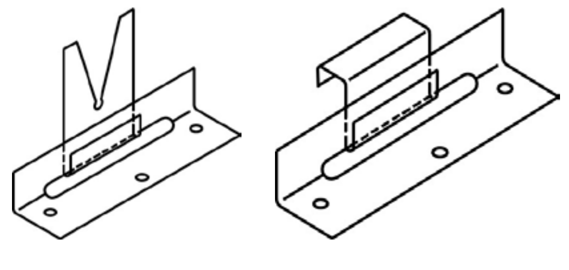
A zone of fixed clips is necessary on a roof covered by long strips to secure the copper to the roof. Sliding clips allow the copper sheet to move, expand and contract.

The movements of the strips are assumed to originate from the fixed zone or centre of movement (shaded area in the figure below; sliding clips are placed in the unshaded areas). The fixed zone should be 1.5 to 3 m in length, depending on the total strip length. In the case of steeply sloping roofs, it is appropriate to place the fixed zone at ridges. If the fixed zone is placed in the middle of the roof, one strip length can be laid upwards from the fixed zone, and another can be laid downwards from it.

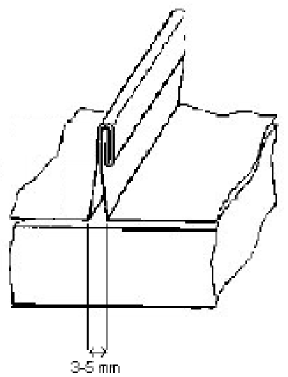
If the strips are locked in position at more than one point lengthwise along the roof, or if the recommended strip lengths are exceeded, an expansion joint must be placed between these points. The fixed zone and expansion joint must be positioned in the same place along the roof.



POSITION OF THE FIXED CLIPS WITH INCREASING ROOF PITCH



SLIDING CLIPS



PLAY IN THE SEAM TO ALLOW FOR LATERAL EXPANSION

INTERRELATIONS WITH BUILDING PHYSICS

GENERAL CONSIDERATIONS

When considering building physics related to metal sheet covered structures the most important factors are heat transfer and vapour diffusion through the building components that form the roof or the wall. Proper insulation and vapour control are important for low energy, healthy and comfortable buildings.

The roof can be heat insulated in different forms, e.g. with the traditionally used insulating layers placed between and/or under the rafters or with heat insulating panels designed specifically for sheet metal roofing, which at the same time serve as the substrate of cladding.

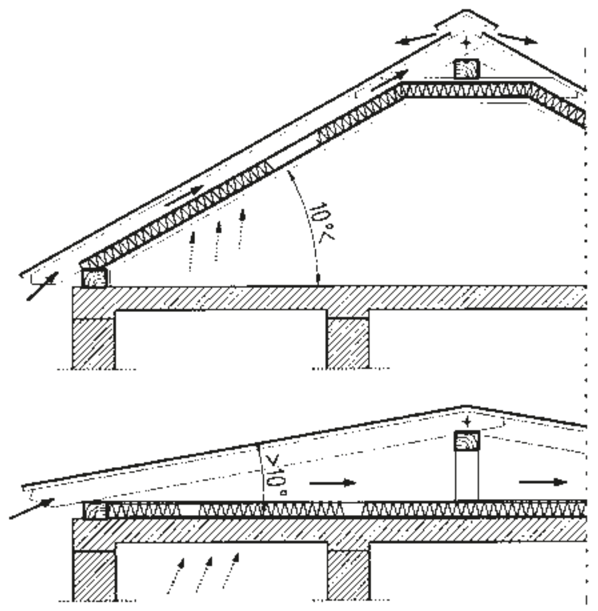
The partial pressure of water vapour is dependent on room temperature and relative humidity. If there is a temperature difference between in- and outdoors, a difference in pressure arises and different potentials tend to seek equilibrium in the direction of the pressure drop – the moisture diffusion starts from inside out.

If the partial pressure of water vapour remains below the maximum possible partial pressure (dependent on temperature) throughout the whole building structure condensation does not occur. As a simple rule building is free of condensation, if:

- The thermal insulation of construction layers increases from inside to outside: thermal transmittance (U value) becomes progressively smaller from inside to out.
- The water vapour diffusion resistance of the construction layers decreases from inside to out.

When considering a metal clad building, the first impulse is that this principle is reversed: the metal layer on the outside has the best thermal conductivity and the highest water vapour diffusion resistance. There are two basic ways to solve this problem: ventilated structures and non-ventilated structures.

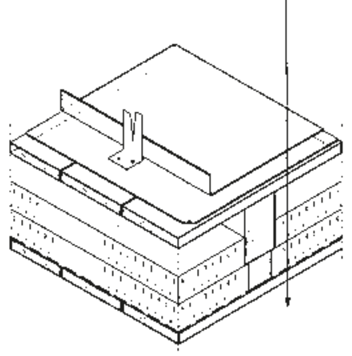
PRELIMINARY DRAWING OF A VENTILATED ROOF



VENTILATED STRUCTURES

In case of this solution the outside shell of metal cladding is separated from the insulating and load bearing construction by a ventilating air gap connected to outside air by inlets and outlets. This ventilated air gap works with natural ventilating effect; thus its effectiveness is dependent on following key factors:

LAYERS OF ROOF – VENTILATED STRUCTURE



POSSIBLE LAYER SYSTEM

VENTILATION PATH AND HEIGHT (SLOPE)

Ideally, the best thermal current occurs with the stack effect where the relationship of height and distance is most favourable. As the slope becomes flatter, this relationship becomes more and more unfavourable. The stack effect no longer occurs in roofs pitched below 10°, so in case of such roofs ventilation must go crosswise, utilising wind pressure.

LOCATION AND FORM OF VENTILATION OUTLET OPENINGS

Inlets must be located at the lowest and outlets at the highest point and must be adequately sized.

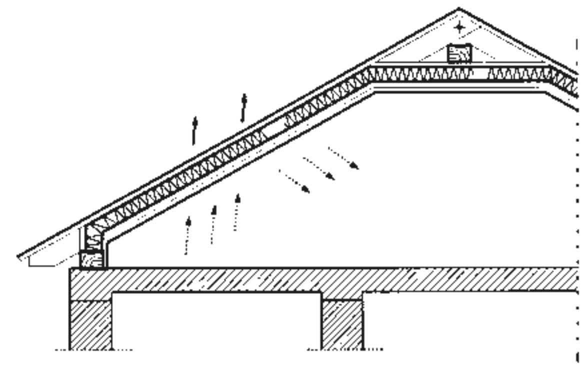
LENGTH OF THE VENTILATION AREA

Generally, in ventilation spaces greater than 15m long the air current will come to a standstill. If ventilation path length is longer it must be divided into shorter sections.

VENTILATION LAYER GUIDES

A narrowing of the layer, obstructions, interruptions and direction changes in the ventilation layer could cause the air current to stall, which would lead to moisture build up.

PRELIMINARY DRAWING OF A NON-VENTILATED ROOF



POSSIBLE LAYER SYSTEM

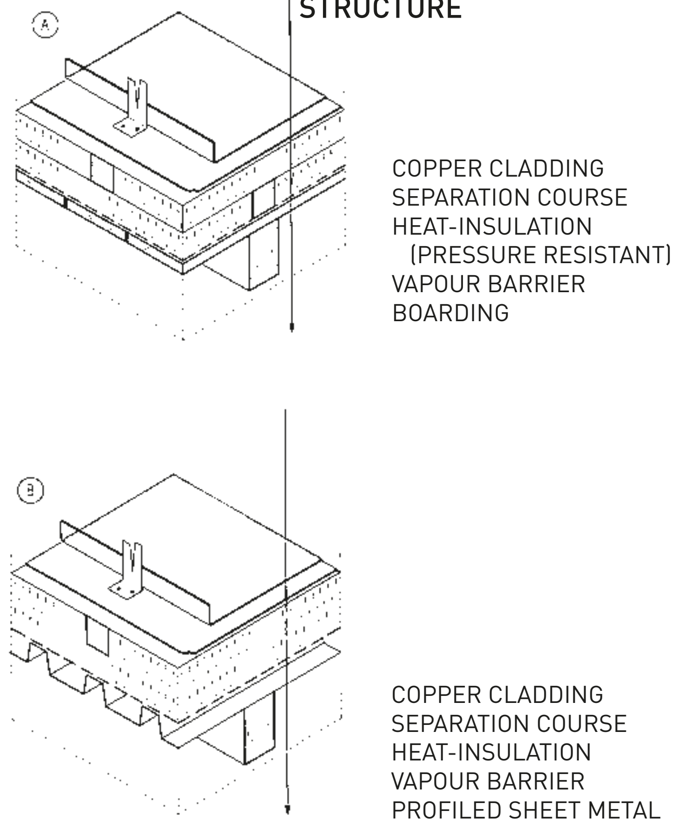
NON-VENTILATED STRUCTURES

Copper has been installed on non-ventilated roofs for many years for design purposes or under conditions that do not allow ventilation (e.g. large, low-pitched roofs). When properly constructed, the non-ventilated structures offer many advantages for sophisticated roof geometry, well insulated buildings in modern architecture.

The efficiency of non-ventilated metal cladding is essentially dependent on the following key factors:

- Installation of an effective vapour barrier (sd ≥ 100m) that eliminates the diffusion of vapour into the roof structure.
- Choice of metal for the cladding which can withstand small amounts of moisture in the roof structure without corroding. Copper is especially well suited because it does not suffer from underside corrosion.
- If an underlay beneath the copper sheeting is used It must be a breathable membrane otherwise condensation could form underside of the underlay.
- Carefully avoid possible damage of the vapour barrier layer during or after installation. It may cause the penetration of moisture into the structures.

LAYERS OF ROOF – NON-VENTILATED STRUCTURE



EVALUATION

In conclusion it is clear that in individual cases a decision must be made depending on the building requirements as to which kind of structure should be used – either ventilated or non-ventilated.

In summary, let us suggest the usage of ventilated roofing systems in cases of simple roofs unbroken by superstructures and in cases of great slope angle, while the usage of non-ventilated roofing systems is better in cases of more complex forms.

Royal Academy of Music, London, UK
Architect: Ian Ritchie Architects
Photo © Adam Scott

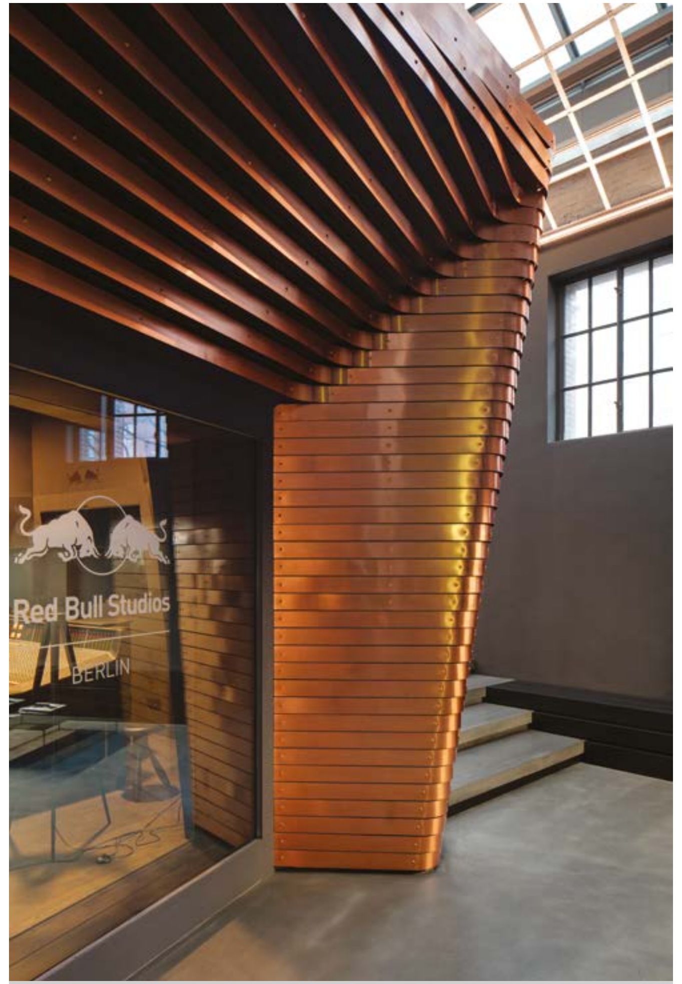
The location is subject to some extreme weather, sun and snow, large temperature oscillations, solar radiation and strong storms.

INTERIOR DESIGN

Besides its popularity in architecture as a thoroughly modern material for roofing, facades and other external architectural elements, copper forms part of the designer's palette for interior items such as door furniture, handrails and contact surfaces (where its hygienic characteristics are also important), corner mouldings and detailing (to provide continuity throughout an entire building), and feature elements like fireplaces and light fittings.

Copper and its alloys are ideal for interior design instead of, or in combination with conventional materials. The surface of copper can be varnished or waxed to preserve its distinctive colour and shine indoors.

Nowadays, there is also a growing trend for wider, innovative uses in interior design inspired by copper as wall, ceiling and floor coverings or copper-clad sculptural staircases. Additionally, copper mesh and perforated copper sheets can be used internally as partitions, screens and other interior elements. Three-dimensional shapes also provides endless opportunities in interior design and decoration.



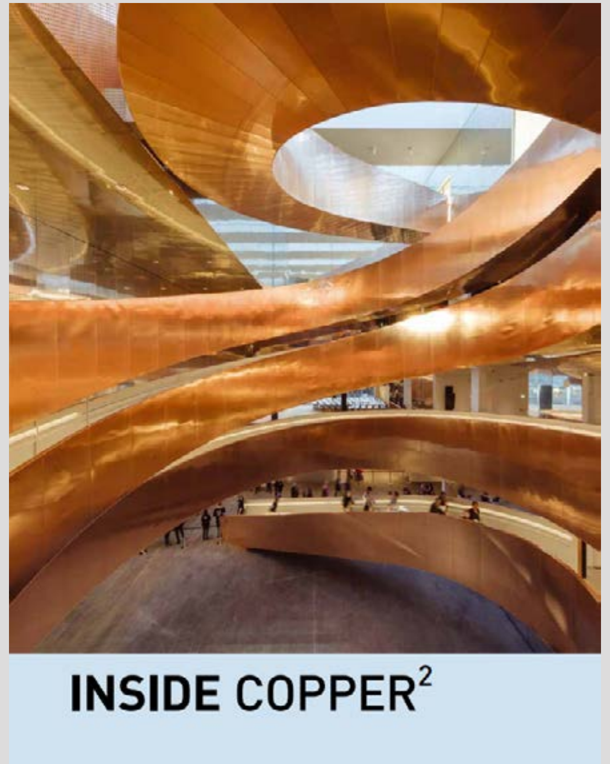
Red Bull studio, Berlin, Germany
Architect: Optimist Design
Photo © Jan Bitter for Optimist Design

A visual rhythm has been created by forming the shape of the copper strips into an undulating sequence to represent the natural flow of sound and music.

Copper Architecture Forum

INTERIOR SUPPLEMENT IN COPPER ARCHITECTURE FORUM MAGAZINE

The Copper Architecture Forum design supplements issued under the title Copper Inside are celebrating the diversity of applications of copper and its alloys inside buildings. Order your free printed copy or read them online attached to issue 39 and 43: copperconcept.org/en/copper-forum or scan QR code.



Copper in Architecture Awards

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Awards 2017 winner Maersk Building, Copenhagen, Denmark
Architect: C.F. Møller - Photo © Adam Mørk

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