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# Contents

# Foreword

## The invisible limits of bird flight

When we see birds flitting from tree to tree or circling high in the sky, we sometimes long to be able to do the same. Yet we're hardly aware of the dangers that lie in wait for birds. One major threat is glass windows – such a normal part of our modern lifestyle that we can scarcely imagine life without them. The United Nations (UN) even declared 2022 the 'International Year of Glass' in recognition of the important role it plays in our society. However, glass also has its downsides: while birds mainly use visual cues for orientation, they are not able to recognise glass. Millions of birds die every year in collisions with glass, making this one of the greatest bird conservation problems in urban areas. With the constant expansion of urban areas and the increasing popularity of glass as a building material, the problem is becoming ever more acute.

Yet simple measures could prevent these deaths. Previous issues of this publication in 2008 and 2012 met with great interest, and their recommendations are increasingly being implemented. In the meantime, however, there have been numerous new findings and products, and thus a completely revised edition has become necessary. As the publisher of this brochure, the Swiss Ornithological Institute in Sempach is eager to raise awareness of this topic both in Switzerland and abroad. Like its predecessors, this new edition is the result of a well-established twenty-year collaboration between scientists and field experts from Germany, Austria, and Switzerland. While the brochure is designed for German-speaking countries, it has also been translated into other languages for use in other European countries. The information compiled here will help architects, planners, builders, and glass manufacturers to find bird-friendly solutions for new buildings. The brochure also suggests measures to retrofit existing buildings.

Much remains to be done in both the private and the public sphere. We are grateful to all those devising imaginative and aesthetically interesting ways to prevent the deaths of countless birds. And the birds are grateful too!

Peter Knaus
Director of Conservation, Swiss Ornithological Institute in Sempach

# 1 Glass, a problematic material

Over the last 50 to 100 years there has been a drastic decline in the quality of natural and seminatural landscapes in Central Europe as habitats for birds. In contrast, human settlements – especially cities – still offer diverse and favorable conditions. Wooded areas in parks, cemeteries, undeveloped plots and other habitats with trees are particularly important as they provide shelter to numerous breeding and migrating birds.

**Every year glass surfaces cause millions of fatalities**

Glass as a risk factor for birds has become increasingly prominent in recent decades. Many common urban species are killed in collisions with this material, but the casualties often include migrants and visiting foragers such as the Eurasian Woodcock, Common Kingfisher, Eurasian Sparrowhawk, and Northern Goshawk. Even outside cities, however, glass is increasingly becoming a deadly trap. A statistical projection by Germany's state bird protection agencies estimates that about 100-115 million birds per year are killed in glass collisions in Germany alone. This equates to more than 5 % of all bird individuals occurring in Germany each year[1]. The figures are probably similar for other industrial countries with comparable human population densities. For the USA, for example, projections have estimated bird mortality from glass collisions at 365 to 988 million annually[2]. Migratory birds now encounter glass in many places, including the Mediterranean region, during their migration. Since migratory birds are at above-average risk worldwide, glass could be another factor negatively affecting their populations.

**The surface area covered by deadly glass is growing rapidly**

Of course birds face other threats. Habitat loss is regarded as the major factor reducing bird populations. Millions of migratory birds are shot or caught in traps and nets every year in many Mediterranean countries; 700 kilometres of mist nets have been found along the Egyptian Mediterranean coast alone. In comparison, however, we must bear in mind that about 85 million tonnes of flat glass are currently produced worldwide per year and 30-40 % of this is used for building envelopes. With an average thickness of windows and façades of 1-2 centimetres, this annual increase in glass corresponds to an area of about 800 million square metres – enough to build a glass wall 100 metres high and 8,000 kilometres long – from Paris to Beijing. And that's just the annual increase! Glass surfaces now pose a risk to birds all over the world.

**The silent death of our birds**

Bird fatalities from collisions with glass are completely unintentional – and most of them could be avoided. Why are we still so unaware of this problem, despite its vast scale? We would notice evidence of bird collisions a little more if we were to take a closer look at some glass surfaces. Larger birds (especially pigeons, woodpeckers, and birds of prey) often leave behind plumage imprints when they collide, and even a few inconspicuous feathers can be evidence of a collision. However, most birds, especially smaller ones, do not leave visible marks on the glass, and their carcasses are usually disposed of quickly – by foxes, rats, cats, and martens at night, and mainly by crows during


*Glass façades, each with a surface area of many hundreds of square metres, are being built all over the world, leading to a sharp global rise in bird mortality. A fundamental rethink is required to prevent a further increase in bird-glass collisions.*

the day. Indeed, these carrion-eating animals come by regularly to patrol particularly 'productive' glass façades. Cleaning personnel and caretakers are also quick to remove bird carcasses. The drastic underestimation of bird collisions often only becomes apparent through intensive systematic studies.

**It doesn't always have to be glass**
Glass is a comparatively inexpensive building material. However, it also has disadvantages for humans such as the reflection of sound and solar radiation, the heating of interiors in summer, heat loss in winter and the high energy consumption needed for its production. Furthermore, its impact on biodiversity compels us to fundamentally question the use of this material. We should think critically about the use of glass on buildings on a case-by-case basis before creating 'transparent' designs. If designs do involve a large amount of glass, there are simple ways to drastically reduce bird collisions without significantly restricting the view. This brochure will explore these possibilities. Purely aesthetic design aspects must not come at the expense of biodiversity!

**Light pollution as a bird killer**
The dangers of glass are not restricted to daylight. Countless migratory birds collide with windows and light sources at night after being attracted by excessive illumination. This light pollution has many other effects on wildlife such as bats and insects, but also on humans. With this in mind, we will show some simple measures that can be used to reduce these hazards.

*Collision victims collected during the 2017 spring and autumn migration in some areas of Toronto, Mississauga, and Markham by FLAP (Fatal Light Awareness Program) Canada volunteers.*

[1] LAG VSW – Länderarbeitsgemeinschaft der Vogelschutzwarten (2017): Der mögliche Umfang von Vogelschlag an Glasflächen in Deutschland – eine Hochrechnung. *Berichte zum Vogelschutz* 53/54: 63–67.

[2] Loss, S. R., T. Will, S. S. Loss & P. P. Marra (2014): Bird-building collisions in the United States: Estimates of annual mortality and species vulnerability. *Condor* 116: 823.

# 2 Glass as a bird trap

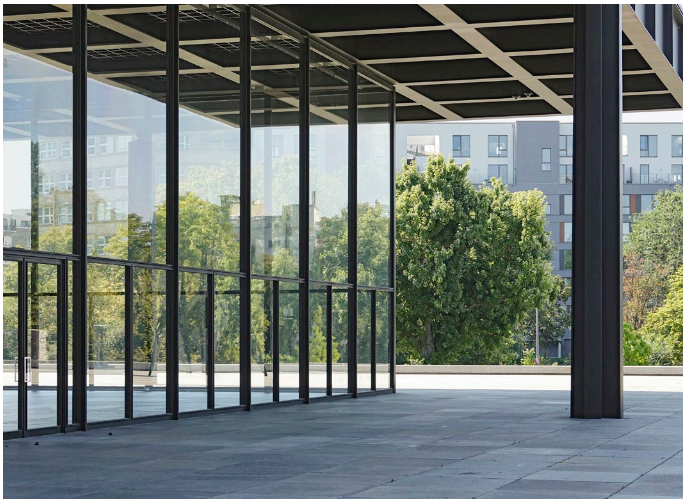
**Transparent architecture at the expense of birds**
Glass occupies an important position in contemporary architecture. Its transparent and 'airy' properties give it an often-mentioned lightness. From an architectural point of view, it enables interaction between indoor and outdoor spaces, creating fluid transitions and a connection with the building's surroundings, while at the same time providing a pleasant climatic and physical separation. Seen from the outside, glass offers another property that is often used deliberately: the smooth surface reflects its surroundings and enables an interplay with the architecture of neighbouring buildings, the natural environment, and the clouds. At night, interior lighting shines through glass to the outside, creating the architecturally desired effect of luminescent bodies.

From a bird conservation perspective, however, transparency, reflection, and illumination have a disastrous downside, posing deadly risks to birds and costing billions of avian lives every year.

## 2.1 Transparency

**The invisible wall**
Birds perceive obstacles visually – just like humans. What makes an obstacle visible is its outer contours and its inner texture[3], and glass lacks both these things. Thus birds (like humans) are unable to visually distinguish between transparent glass walls and air. Our human experience prepares us to expect glass at certain points in a building. Having internalised glass as part of our lived environment, we unconsciously take our cue from structural components such as building edges, certain recurring window and façade structures, fixing elements, etc. And yet, even for humans, glass is marked at eye level on many public buildings, because accidents can happen in unfamiliar surroundings. Birds do not have this experience. If there is a pane of glass in front of an attractive habitat, e.g. a copse of trees, a bird flying towards it cannot recognise the glass as a solid object. Birds also move through the air faster than humans on the ground. This speed turns glass into a trap, most often a fatal one.

Transparency, as opposed to reflection, occurs when the area behind the glass is more or less as bright as the area in front of it. Such conditions are usually found at free-standing noise barriers, glass balustrades, public transport shelters etc. Buildings also have transparent areas, such as glass passageways and corner glazing, through which birds can see the sky or

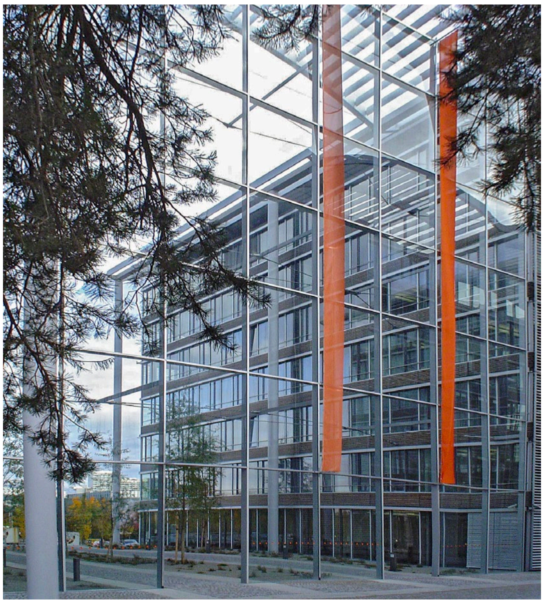


*Transparency and openness as the epitome of modernity characterise the architecture of this art gallery, the Neue Nationalgalerie, in Berlin. For birds, the unobstructed view through the glass building becomes a deadly trap.*

*Padel tennis courts are sometimes surrounded by transparent plexiglass. Evidence from Spain, Italy and other European countries has shown numerous bird collisions with these walls.*

green structures. Conservatories, glazed terraces and other structures for wind protection are therefore also extremely dangerous for birds.

**Conclusion:**
**Glass as a light-transmissive building material offers fascinating possibilities, but also presents a widely underestimated danger to all animals that use vision for orientation. As an invisible barrier, glass injures and kills birds.**



*When first constructed, the sprawling 'Uptown Munich' building complex, with its fully glazed façade and large transparent noise barriers, posed a deadly threat to birds. It has since been fitted with markings to deter birds*

## 2.2 Reflection

A bird that sees an uninterrupted reflection of trees and bushes in a pane of glass is unable to recognise the glass as an obstacle.

**What causes reflections on glass?**
If the area behind a pane of glass is darker than the area in front of it, reflections appear on its smooth surface. This is often the case in windows and building façades. Light conditions behind windows are normally more diffuse and much less bright than outside, except at night when interiors are lit. Because our eyes adapt to the ambient light, we perceive interiors as being bright, even if the light intensity is only a fraction of the daylight outside the window. The 'daylight index' indicates the ratio of outdoor daylight intensity to indoor light intensity. At workplaces, it should be between 1 % and 3 %. So the levels of light intensity of comparable surfaces in buildings are often only one hundredth of those outdoors.

This means that there are often substantial differences between the illumination of objects outdoors and indoors (tab. 1), and thus in the reflection of light towards a glass pane. Specular reflections on the outer glass surface only disappear when bright objects indoors direct more light outwards than objects outdoors direct towards the panes. As a rule, this is only the case with objects directly illuminated by sunlight within close range of the windows.

When the sky is overcast and outdoor light is diffuse, the bright reflection of the sky or light-coloured

*Table 1: Typical light intensity levels of indoor and outdoor objects in lux (lx). (Source: Wikipedia, 1 June 2022)*

| **Light conditions** | **Typical light intensity** |
|---|---|
| Clear sky, summer's day sun elevation 60° (noon) | 90 000 lx |
| Overcast sky, summer's day | 60 000 lx |
| Overcast sky, winter's day | 3500 lx |
| TV studio | 1000 lx |
| Office workplace | 500 lx |
| Interior in daylight | 50 lx |

[3] Gibson, J. J. (1958): Visually controlled locomotion and visual orientation in animals. *Br. J. Psychol.* 49: 182–194.

*The smooth surface of glass casts reflections whenever the background is less illuminated than the foreground. Additional coatings on the glass façade can create higher-contrast reflections. For birds, the reflections of both trees and skies give the impression of open space.*

*Although interior blinds and light-coloured curtains behind the windows can reduce reflections, they often still occur. Such measures cannot be expected to provide effective protection against collisions, especially as blinds are not permanently closed.*

walls on the panes is predominant, while less reflective objects such as trees show up as silhouettes. But even in weak daylight, a building's interior remains in darkness and reflections predominate – or a mixture of reflections and glimpses of the interior. On sunny days, very realistic, high-contrast and seemingly three-dimensional reflections appear.

**Without marking, low-reflection glass offers no protection for birds**

Given these extreme differences in light between inside and outside, it is clear that even with highly anti-reflective glass with only 2 % external reflection, realistic reflections can still occur in sunlight. The use of low-reflection glass alone and without additional

**External reflectance**

An uncoated float glass pane reflects 8 % of the light striking it (incident light), 4 % on each of the two surfaces. With multi-layered insulating glass, the external degree of reflection increases because of the cumulative reflective values of the different panes. The external reflectance can be reduced with special coatings; however, many coatings can increase the external reflectance. Sun protection films often reflect 25 % and sometimes up to 60 % of the incident light. A conventional silver mirror reflects between 80-90 % of the visible light, whereas UV is reflected with less intensity. In the choice test, collision risk increases with reflection; birds are three times more likely to fly towards a silver mirror than an unmarked float glass pane.

*In outdoor art installations, mirrors are often used for special effects without the artists being aware of the danger they pose to birds and other organisms such as insects. Doug Aitken's temporary metal installation Mirage, in Gstaad (Switzerland), was fitted with a bird-protective pattern of black stripes right from the start.*

marking therefore does not constitute bird protection (chapter 4).

Nevertheless, glass with a low degree of external reflection is still helpful in combination with other measures, since the collision risk increases with the degree of reflection. Experiments (section 3.2.2) have shown that birds fly towards a silver mirror (>80 % reflection) three times more often than uncoated single glazing made of float glass, because the mirror produces higher-contrast reflections. With insulating glass, multi-layered reflections often result in blurred or slightly distorted mirror images. However, experiments have so far failed to prove that the distorted or blurred reflections from insulating glass reduce the number of collisions.

**Conclusion:**
**Reflections are visible on the smooth surfaces of windows and façades in almost all daylight conditions, since less than one per cent of the outside light is reflected back from interior spaces.**

## 2.3 Bird activity, building surroundings and architecture

**Factors influencing the risk of collision**
The light-dependent properties of glass – transparency and reflection – are largely responsible for bird collisions with glass panes both in daylight and at night. The following sections discuss factors that have nothing to do with the properties of glass, but which significantly influence the collision risk. These are flight activity and the attractiveness of a building's surroundings (biological components), and the dimensions and arrangement of glass façades (architectural components).

### 2.3.1 Activity

**The number and mobility of birds are often underestimated**
The birds we are most familiar with, such as finches, tits, sparrows, or woodpeckers, attract our attention as they move from bush to bush and tree to tree, often calling or singing as they do so. Other species, such as many warbler species, tend to go unnoticed and are far less familiar to us. This is because they are adapted to life in dense vegetation and rarely leave the vegetation that provides their cover. Both the number of birds present and their mobility are easily underestimated, and we perceive their collisions with glass as isolated and completely unexpected incidents. But birds are among the most mobile organisms on earth, in constant motion as they search for food or react to disturbance by enemies. Many species change continents with the seasons. Migrating birds make stopovers in southern and central Europe, often for several days or weeks. This means that more birds are present in spring and autumn, which is reflected in increased findings of glass collision casualties[4].

**Bird activity depends on numerous factors**
Many things influence flight activity around a single building: the behavioural characteristics of the bird species present at the time, the time of day and season, weather, habitat quality and current food supply, distance between feeding, perching, resting and roosting sites, and frequency of disturbance by enemies. But even in seemingly inhospitable areas with very little vegetation in the interior of large cities, fatalities occur – in some cases mass fatalities. The list of collision victims includes species that one would not expect to find in settlement areas, such as inhabitants of wetlands or northern forests. These birds only enter urban habitats during bird migration seasons.

**Assessing the risk potential of a planned building requires special expertise**
The high variability of bird activity makes this factor difficult to assess. With specific ornithological expertise, it is possible to make predictions of particularly high bird activity, but it is much more difficult to predict activity densities that are low enough to be unproblematic. Such predictions require complex evidence. In general, the mere presence of glass surfaces entails an above-average risk to birds even at average activity levels, given that their high

[4] Steiof, K., R. Altenkamp & K. Baganz (2017): Vogelschlag an Glasflächen: Schlagopfermonitoring im Land Berlin und Empfehlungen für künftige Erfassungen. *Berichte zum Vogelschutz* 53/54: 69–95.

glass-related mortality is not only explained by certain high-risk sites and glass surfaces, but primarily by the widespread use of glass panes.

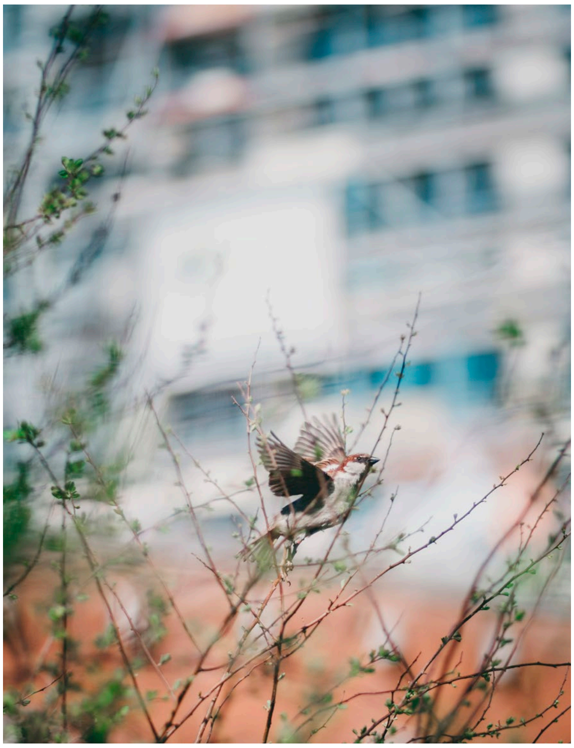
**Conclusion:**
**The frequency of flight movements is a decisive factor when it comes to the risk of birds colliding with glass. This frequency is extremely variable, depending on location factors and time of year, and can only be predicted to a limited extent. Even an average level of activity means an above-average risk to birds.**

### 2.3.2 Surroundings

**Urban greenery attracts birds**
Half of the world's population lives in urban agglomerations. However, those who can afford it settle in green areas and look for homes with gardens in near-natural surroundings. As climate change gathers pace and cities become hotter, not least because of the types of buildings constructed, greenery in urban spaces is becoming more and more important. In Central Europe, parking spaces are increasingly being replaced by street trees, which provide shade, filter dust from the air, and give structure to the streetscape. Green space close to housing allows contact with nature and with its most conspicuous representatives, birds.

**Glass is particularly fatal near trees**
Although contact with birds is seen as a positive thing that enhances residential areas, glass is often used carelessly in green, near-natural habitats – not only in windows and building façades, but also in glass fences, waiting areas for public transport, land art installations and much more.

Even in inner cities with little vegetation, collisions occur – and the casualties include rare bird species. In general, however, the likelihood of a bird colliding with a glass surface is associated with the abundance and height of vegetation in the surrounding area. Studies have shown that the vegetation in the immediate vicinity of buildings plays the greatest role. In the presence of trees more than two storeys high, the risk of collision is 3.6 times higher than for buildings in a treeless environment[5,6]. A direct positive risk correlation has also been proven for glass façades up to 100 m distance from trees[7]. Sustainable urban planning increasingly includes measures to preserve, protect and promote biodiversity and to improve the urban climate. The catchphrase 'animal-aided design' (AAD)[8] refers to the deliberate creation of structures that serve animals as feeding areas, nesting sites or hiding places. However, without simultaneous measures to prevent bird collisions, the promotion of biodiversity can be counterproductive, as it only attracts more birds into an ecological trap.



*For us, sparrows are the epitome of liveliness. The more birds there are around a building, the more likely it is that transparent or reflective glass surfaces will lead to fatalities.*

*Great Spotted Woodpeckers are regarded as typical forest dwellers, yet many of them travel considerable distances in urban areas every day, and they are frequently killed in glass collisions.*

**Rivers guide birds through large cities**

It is not only in the immediate vicinity of parks, groves of trees and gardens that glass must be used with great care. There are often specific biotopes, especially wetlands and expanses of water, adjacent to settlement areas.

Ornithological hotspots, often designated as nature reserves or European protected areas, have an impact on the wider surroundings, and may generate 'flight connections' between these places. These are relevant even for small birds with low flight altitudes. Overlooking this can lead to an underestimation of the risks. Rivers, for example, offer guiding pathways through towns and cities. Moreover, their insect populations often make them the last refuges with available food in the event of bad weather during bird migration. They are therefore of interest not only to bird species that normally live in or near water, but also to songbirds that otherwise search for food in surrounding areas. So the question of a building's 'surroundings' is complex and should not be considered solely in terms of the immediate vicinity.

**Panoramic windows kill what they want to display**

In cases where architecture aims to create proximity to nature, the natural features of the surroundings and the presence of wildlife often have a direct influence on building design. Architectural concepts that construct fluid transitions between safe, clean, air-conditioned living space and wild nature are particularly problematic. Residential buildings, wellness facilities, and hotel complexes are often constructed with an extremely high proportion of glass surfaces to force their way into the idealised natural environment. In seeking to eliminate the visual boundary between human habitation and wilderness, they create a hard physical boundary. Glass is elevated to a synonym for proximity to nature, but instead becomes a threat to the very nature we yearn for.

This is also evident in tourist facilities in the mountains, where large quantities of glass are used to provide panoramic views. Even cable car and lift stations are often designed with a glass outer shell. In ski resorts, these are often only in operation for a limited period of the year; outside the tourist season they perform no useful function, but are a constant danger to birdlife. Birds that live in mountain forests or in alpine habitats above the tree line are highly mobile and often have to cope with poor visibility. This frequently results in fatal collisions with glass structures. The list of collision victims ranges from Goldcrests and Coal Tits to Black Grouse, and also includes birds that migrate across the Alps.

*Façade greening on the Musée du Quai Branly in Paris. Such measures, implemented to support biodiversity and improve the city's climate, must go hand in hand with efforts to prevent bird collisions.*

**Conclusion:**

**Glass is often associated with proximity to nature in buildings. But the more natural the surroundings are, the more problematic glass becomes. Exclusive forms of housing and tourist facilities with panoramic windows can be particularly dangerous for birds. In order to assess collision risks, long-distance effects and fluctuations in activity throughout the year must be taken into account.**

[5] Klem, D., C. J. Farmer, N. Delacretaz, Y. Gelb & P. Saenger (2009): Architectural and landscape risk factors associated with bird-glass collisions in an urban environment. *Wilson J. Ornithol.* 121: 126–134.

[6] Kummer, J. A., E. M. Bayne & C. S. Machtans (2016): Comparing the results of recall surveys and standardized searches in understanding bird-window collisions at residential houses. *Avian Conserv. Ecol.* 11: 4.

[7] Loss, S. R., S. Lao, J. W. Eckles, A. W. Anderson, R. B. Blair & R. J. Turner (2019): Factors influencing bird-building collisions in the downtown area of a major North American city. *PLoS ONE 14*: e0224164.

[8] Hauck, T. & W. Weisser (eds.) (2019): *Animal-Aided Design im Wohnumfeld. Einbeziehung der Bedürfnisse von Tierarten in die Planung und Gestaltung städtischer Freiräume*. Kassel and Munich.

## 2.3.3 Architecture

**Integrating bird protection into building design**
While the original function of glass was to provide light for interior spaces, it is now used as an architectural design element in almost all building sectors. A building's architecture influences the threat it poses to birds in two ways: on the one hand with the sheer amount of glass surface in its outer shell, and on the other hand with options for spatial arrangement and with the structure of the building and its glass surfaces.

**Particular hazards**
In principle, the risk of collision increases with the amount of glass area coverage. However, if bird activity is high and the surroundings are attractive, even relatively small glass surfaces on buildings can pose a significantly increased mortality risk. From the outset, however, this risk is particularly high on transparent building elements such as noise or wind protection walls, glass balustrades, passageways and bridges, and corner glazing.

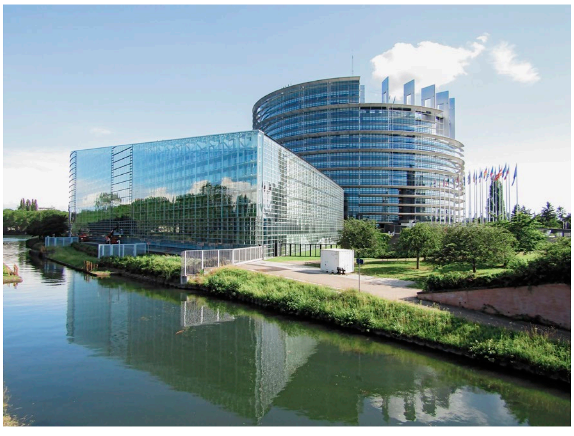
Especially in an urban environment, the arrangement of individual buildings above a certain height influences the flight paths of birds. If birds are led into a dead end or narrow passage by parallel or converging building structures, the risk of collision increases as soon as reflective or transparent surfaces suggest a way out. This is also the case with completely enclosed courtyards. The effect is exacerbated in narrow courtyards, because birds have difficulty taking off at a steep angle. Here disorientation and panic can lead to increased collisions even with smaller glass surfaces.

*To be able to assess collision risks, it is necessary to consider a surrounding area of several hundred metres. In the centre of Berlin, numerous bird collisions have been documented at buildings such as the Paul-Löbe-Haus, the central railway station, and the Neue Nationalgalerie, as well as at Potsdamer Platz. The proximity to the River Spree and the Tiergarten brings life to large areas of the city (Avda/avda-foto.de).*

**Building height and collision risk**
Most collisions in daylight occur on storeys up to just above tree-top height (approx. six storeys), as bird activity is greatest in these areas. There is some evidence to suggest that collision risk decreases significantly with increasing building height. This has not yet been conclusively proven, however, as a systematic investigation of these building areas is difficult. During the day, only a few bird species fly at great heights – to hunt prey or to cover substantial distances. Nevertheless, bird collisions have also been recorded on the higher parts of façades, not least on roof terraces at the tops of very tall buildings.

**Artificial light attracts birds**
Hazards related to architecture also include interior lighting which penetrates through glass to the outside, as well as external illumination at night. Luminescent architectural statement pieces, but also simple night-time lighting of corridors or offices, create hazardous situations, especially during migration periods. In Berlin, victims of night-time collisions have

*Architectural concepts which construct fluid transitions between indoors and outdoors and suggest that people can be both indoors and in the wild create deadly barriers for everything that flies.*



*The imposing glass façade of the European Parliament in Strasbourg, on the banks of the River Ill and the Marne-Rhine Canal, covers 13,000 square metres and is meant to symbolise the democratic transparency of the European Union.*

*Birds perceive long strips of windows and reflective glass surfaces as opportunities to fly through the structure of the building. Individual subdivisions within glass surfaces do not reduce the risk of collision.*

*In green inner courtyards or areas of buildings which are enclosed from multiple sides, the risk of collision with glass surfaces increases. Vegetation attracts birds flying over the sea of buildings, but once they are inside they can have trouble taking off at a steep angle and flying away.*

been registered near ground-level before dawn, having flown towards points of light such as digital billboards, which were significantly brighter than their surroundings. The danger of bird collisions with glass also increases when the building façade is illuminated. Although nocturnal bird migration tends to take place at high altitudes, certain bird species fly at lower altitudes if there are headwinds, precipitation or fog. So it is not just towers and skyscrapers that are problematic. Such conditions can sometimes even lead to mass collision events, which are reported by the local press (chapter 5).

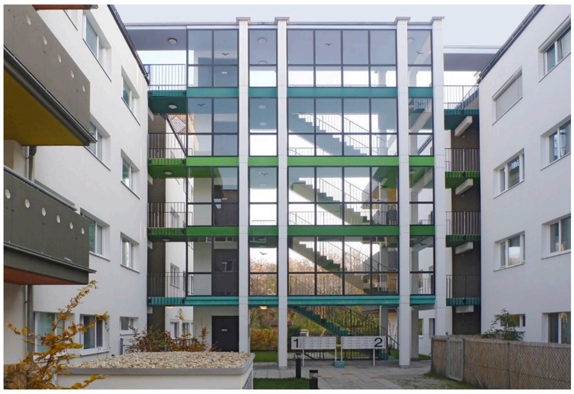
**Conclusion:**
**Bird protection should be as self-evident as fire safety, fall prevention, soundproofing and insulation. We believe that architecture has a duty to contribute to biodiversity conservation. In addition to resource-efficient building materials, a sustainable energy concept and a design that works in harmony with its surroundings, a bird-friendly building design is also vital.**


*Glass parapet several metres high at the top of a skyscraper. Birds not only collide with the glass from the outside, but also hit the panes from the inside after ending up within the enclosed area.*

## 2.4 What not to do – examples of dangerous glass buildings

Anyone who is aware of the issue of bird-glass collisions will regularly notice situations that endanger birds. Transparent walkways between buildings or wind and noise barriers are typical examples, as are glass façades which reflect shrubs and trees. You don't have to look far to find buildings with such problematic elements.

*Glass windbreaks on bridges and connecting walkways are among the most conspicuous traps for birds. In many places, silhouettes of birds of prey have been stuck onto the glass. While these are ineffective, they confirm that collisions occur on these areas.*

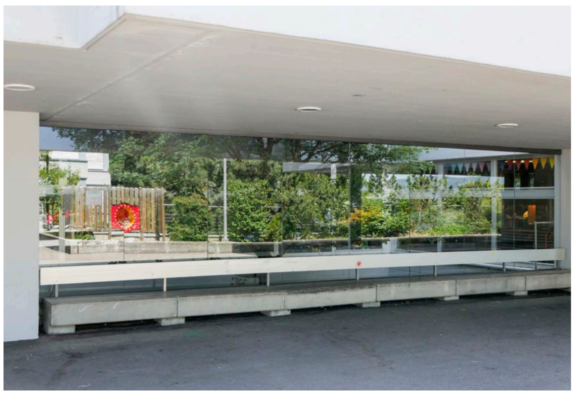


*The danger posed by glass walls and passageways is exacerbated when buildings on either side force the birds towards the obstruction.*

*In green surroundings, glass structures like the entrance to this station are particularly dangerous for birds.*

*Public transport shelters are often made of glass without considering safety measures for birds.*

*Realistic reflections can also be created on glass curtain walls.*



*Although the building protrudes by several metres, clear reflections are still visible on the windows. Shadows cast on windows do not eliminate reflections.*

*Birds often fly very close to the edge of a building without noticing the glass balustrades.*

*Transparent noise protection barriers protect green inner courtyards and gardens or allow people to enjoy the landscape alongside motorways. However, they interrupt birds' flight paths, thereby claiming numerous victims.*

*Transparency combined with a bird-rich environment: Conservatories are often the place where people first become aware of the danger of glass.*

*Especially at dusk, numerous birds are on the move on the banks of waterways. Glass is particularly problematic here for fast-flying water birds.*

*These collision marks clearly show that tinted glass offers no protection against collisions.*

*Works of art made from glass and reflective surfaces do not belong outside, unless they include measures to prevent collisions.*

# 3 Bird-friendly measures

## 3.1 Structural solutions for bird-friendly buildings

**Translucent glass and alternative materials**
Frosted and textured glass and similar polycarbonate products do not create realistic reflections on surfaces. These materials provide comfortable diffused light without casting harsh shadows and are a bird-friendly solution for all building areas intended to provide light but not views.

*A façade of textured and frosted glass allows sufficient daylight into the building, while smaller clear glass windows are used sparingly and selectively only where a view is desired. Atelier d'Architecture Pierre Hebbelinck worked with this exciting mix of different glass structures at the Théâtre le Manège in Mons (Belgium).*

*At the Silesian Museum in Katowice, cubes with a façade of etched glass provide the underground museum rooms with daylight. The abstract glass cubes by the architectural firm Riegler Riewe blend harmoniously into the ensemble of existing historical buildings.*

*The façade of the headquarters of Le Monde in Paris, designed by Snøhetta, is made up of more than 20,000 glass elements. These vary in structure and transparency and are arranged in such a way that they maximise the light in the offices and provide views to the outside in the right positions.*

*The building envelope of this ball sports complex in Ingolstadt, Germany, by Fink+Jocher, consists of a channel glass construction filled with translucent thermal insulation between its two glass profile shells. This enables sufficient light to enter without causing disruptive shadows on the court.*

**Screens and fixed sunshades**

Screens in front of large windows and glass façades can both serve as a decorative element and offer shade from the sun. As long as the parameters for effective bird markings (section 3.2.4) are considered, such façade elements can also provide good protection against bird collisions.

*The Città del Sole ('Sun City') in Rome, by Labics, is a multipurpose facility with public and private functions. Both the design of the façade's aluminium panels and the translucent glass slats on the various buildings provide protection from the sun and for birds in equal measure.*

*The oval-shaped glass pavilion of the Dornbirn Municipal Library, Austria, by Dietrich | Untertrifaller, is wrapped in a structure of 8,000 prefabricated ceramic elements. Arranged vertically and diagonally, the sunshade ornaments are reminiscent of bookshelves and provide pleasant natural light inside.*

*In the west block of the Centre d'Idiomes de la Universitat de València, Spain, by Arkítera SLP, the combination of fixed and movable sunshade slats defines the structure of the façade.*

*When renovating and repurposing the heritage building 'Großenbündt' in Hittisau, Austria, the architects Gruber Locher Architekten provided light to the ground floor by using semi-transparent materials. While the traditional grid windows of the residential wing were retained, the structure of the traditional wooden façade was echoed in the wooden slats over the long ribbon windows on the upper floor. Birds can easily recognise these materials and structures.*

*The glass cube of the Jewish Centre in Munich, by Wandel Hoefer Lorch + Hirsch, is surrounded by a steel structure and a bronze mesh. A triangular pattern of Stars of David creates a special atmosphere in the prayer room through the interplay of light and shadow.*

*The individual buildings of the Graz University of Technology, Austria, by the architectural firm Riegler Riewe, are connected by multi-storey bridges. The façade elements made of steel lattice allow both transparency and the incidence of natural light, while remaining easily recognisable as an obstacle for birds.*

## 3.2 Marking glass surfaces

Markings at potential danger spots are familiar sights as we go about our daily business. The poles of traffic signs and the edges of ledges, steps and construction pits, for example, are marked with bars or stripes in black and yellow or red and white. To prevent us from running into barriers made of glass, these are also marked at eye level, e.g. with block stripe patterns. The same principles can be used to reduce the risk of birds colliding with glass. Findings from research on the perception and behaviour of birds serve as an important basis to develop effective markings that are as inconspicuous as possible to the human eye.

### 3.2.1 How do birds detect obstacles?

**Visual abilities of birds**

To find out how to mark glass effectively, it is important to understand how birds perceive their environment, how they detect obstacles, and how they avoid them. The question here is: how small and discreet can signals be and yet still be recognisable for a bird – especially if it is moving forward quickly and does not have enough time or adequate light conditions to get a clear picture of its surroundings? Birds are more dependent on special visual abilities than other vertebrates, which is why a larger area of their brain is responsible for processing visual stimuli compared to other creatures. They can recognise very fine structures and distinguish colours precisely[9]. But does this also apply in fast flight, in poor light conditions, and for the recognition of glass markings?

**The bird's-eye view**

Only a minority of birds regularly have a proverbial 'bird's-eye view', namely those that circle and soar in free airspace, often without beating their wings. Chaffinches, tits, sparrows, blackbirds and blackcaps, the most common bird species in Central Europe, mostly remain 'on the ground' and under cover of vegetation. They spend much of their time searching for food and must always take care not to fall prey to their enemies. It may seem surprising that although we regard flight as the most distinctive characteristic of birds, the evolution of their vision is not so much geared to a high-resolution view of the flight path, but rather to the detection of food and enemies[10].

**Orientation in flight**

In the natural environment, where solid objects such as trunks, branches and geological obstacles are large in size, flying does not require a particularly high resolution of fine structures. Most birds have laterally positioned eyes (i.e. eyes on the sides of their heads), providing a very large field of vision. In contrast, their spatial, stereoscopic (three-dimensional) vision is limited to narrow zones in front of the beak, which indicates that there are more essential necessities for the birds' survival than investing in a detailed assessment of the flight path. In most birds, the region of highest optical resolution on the retina (the fovea) is laterally oriented.

**Eagle eyes**

Not all birds are equipped with 'eagle eyes': in fact there are only a few birds (of prey) that can see more clearly and distinguish fine details at greater distances than humans. The resolution of the human eye is about twice that of a Common Kestrel, four times that of a pigeon, and 14 times that of a House Sparrow[10]. As brightness decreases, resolution decreases sharply; at dawn it is much lower than when the sun is high in the sky[11,12].

**Conclusion:**

**Avian eyes generally have a lower optical resolution than human eyes. For most birds, sideways vision is more important than forward vision. Fine structures or closely spaced small dots are therefore unsuitable for marking glass. Markings must be of a certain minimum size so that birds can perceive them at a distance and react in time.**

[9] Hodos, W. (1993): The visual capabilities of birds. In: Zeigler, H.P. & H.-J. Bischof (Eds.): *Vision, Brain, and Behavior in Birds*. MIT Press Cambridge (MA).

[10] Martin, G. (2017): *The sensory ecology of birds*. Oxford Avian Biology Series. Oxford.

[11] Lind, O., T. Sunesson, M. Mitkus, & A. Kelber (2012): Luminance-dependence of spatial vision in budgerigars (*Melopsittacus undulatus*) and Bourke's parrots (*Neopsephotus bourkii*). *J. Comp. Physiol*. A 198: 69–77.

[12] Mitkus, M., S. Potier, G. R. Martin, O. Duriez, & A. Kelber (2018): Raptor vision. In: *Oxford research encyclopedia of neuroscience*.

*Birds have very large eyes in relation to their head size, with laterally oriented visual axes. A complete all-round view is more important for detecting enemies and finding food than a sharp view to the front.*

**Obstacle perception**
Birds need to be able to perceive obstacles quickly in order to take evasive action. Frontal collisions with glass panes cannot be avoided by a slight change in direction, but only by changing direction completely, which limits the time available to manoeuvre. Songbirds often move at a flight speed of five metres per second over open ground. Specialised neurons must fire half a second before an impact to trigger a sufficient (unconscious) reaction of the cerebellum and an evasive movement. This rapid response is fundamentally different from scanning a hedge for berries or choosing a brightly coloured mate. An 'optomotor system' is responsible for the special requirements of vision in motion, targeting a landing site, snatching prey, and judging the movement of an enemy[13]. To our current knowledge, this system is colour- and UV-blind[14].

**Colour is not critical**
When it comes to the perception of the habitat and of flight obstacles, little essential information is lost if colour is missing. The essential information is gained from the distribution of bright and dark, and of light and shadow, as well as from contrast lines, because images simplified in this way can be processed quickly. Where colours are important, such as in mate selection, vision is a far more complex process. Another important element here is UV perception, which many songbird species possess.

The reference to the 'colour blindness' of avian optomotor systems does not mean that anti-collision markings should only be black or white. Sensors and neurons that detect the approach of an obstacle and calculate time to collision also have specific spectral sensitivity. This means that they react more strongly to certain wavelengths of light than to others and therefore perceive particular 'colours' more or less intensely. So choosing the right spectral composition for a marking can improve its contrast and thus effectiveness. This is one of the current research tasks in the development of glass markings.

**Conclusion:**
**The perception of movements, seeing in motion and the 'tool' for quick evasive reactions differ greatly from 'seeing without time pressure', both in terms of perception in the eye and neural processing in the brain. The processing of stimuli in connection with movement is thought to be colour- and UV-blind.**

## 3.2.2 Standardised testing methods

**Examination of buildings**
Researching, developing, and testing the effectiveness of markings requires efficient testing methods under standardised conditions and with replicable results. It is virtually impossible to meet these criteria using existing structures, as differences in birds' activity levels and in the surroundings, exposure, composition, and size of glass surfaces prevent comparability. Automated procedures which could be used on many different façades and provide findings on the sequence of events in each collision are not yet available. These have so far failed due to the characteristics of the victims: small, fast, low in contrast, and often flying in poor light conditions.

**Choice tests at the Hohenau-Ringelsdorf Biological Station (Austria)**
To produce comparable, replicable results that will quantify the effectiveness of a marking, a method is required that will enable collisions to be concentrated on limited, easily controlled areas, while keeping the critical variables constant. It should, however, include as many natural variables as possible (e.g. light conditions, the use of wild birds) in a controlled manner. It therefore makes sense to use experimental designs that combine laboratory and field conditions.

[13] Frost, B. J. (2010): A taxonomy of different forms of visual motion detection and their underlying neural mechanisms. *Brain, Behav. Evol.* 75: 218–235.

[14] Campenhausen, M. & K. Kirschfeld (1998): Spectral sensitivity of the accessory optic system of the pigeon. *J. Comp. Physiol. A* 183: 1–6.

The field laboratory that has yielded by far the most knowledge in Europe about the effectiveness of glass markings is the flight tunnel at the Hohenau-Ringelsdorf Biological Station in Austria. The concept of sending birds through a tunnel is based on the understanding that birds will, as a rule, fly from darkness towards light. At the light end of the tunnel is an obstacle that the birds will have to recognise. The more recognisable this is to flying birds, the more often an active avoidance response can be expected. The obstacle in this case is the glass marking. To ensure the reproduction of natural conditions, the birds must not be adapted to the darkness of the tunnel, but to daylight – so they must not remain inside the flight tunnel for more than a few seconds.

**Natural light and natural background**

The Hohenau flight tunnel tests are choice tests carried out under natural light conditions, in front of a natural, homogeneous background. To ensure that the incidence of light and shadows are symmetrical, the 7 m long body of the tunnel is mounted on a pivot and is constantly aligned to the position of the sun. The light falls in the direction of the birds' flight, that is, it always comes from behind. The daylight-adapted birds are placed in the flight tunnel at one end and immediately take off to leave the tunnel at the other end. They fly towards two adjacent panes of glass, one with a test marking (the test pane), the other an unmarked glass pane (the reference pane). The same reference pane is used throughout the tests. The birds are intercepted immediately before impact by a special net with a fine mesh imperceptible to the avian eye. Afterwards, they are released immediately. The flight tunnel is attached to a field station for scientific bird ringing, which means that sufficient numbers of wild birds are available.

*The flight tunnel of the Hohenau-Ringelsdorf Biological Station before the start of the research season, when the vegetation has not yet developed fully. The circular clearing corresponds to the rotation range of the test apparatus, which is mounted on a pivot so that the sun is always behind the birds. The birds are placed in the tunnel at the narrow end and immediately take off in the direction of the test panes (right). They are intercepted by a net, then released unharmed through the side door.*

**Evaluation of the test flights**

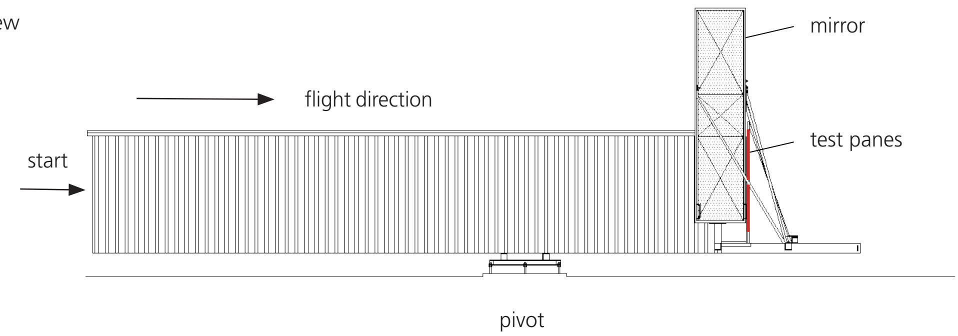
The test flights are evaluated using video recordings. Ineffective test markings can be expected to elicit a random response distribution (i.e. half of the birds fly to the marked pane, half to the unmarked pane). As the markings become more effective and recognisable, more birds can be expected to fly towards the unmarked reference pane. During the Hohenau studies, each tested marking undergoes a minimum of 80 test flights over a prolonged period. This allows its effectiveness to be assessed at different times of day and under different light and weather conditions. The test results were statistically identical in repeated experiments. The results make it possible to compare different markings and rank them in terms of effectiveness.

**ONR test and WIN test**

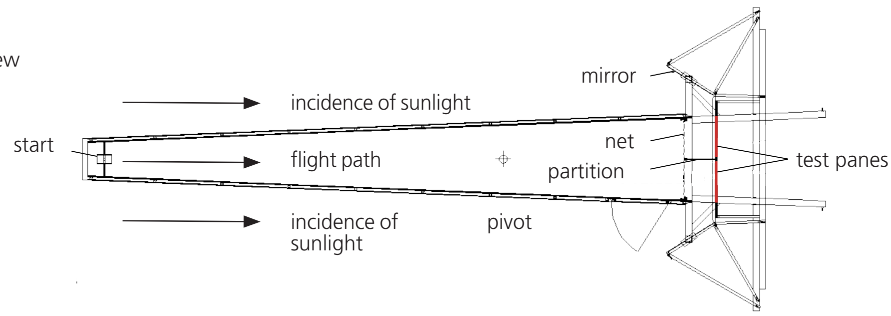
In Hohenau, two modifications of the test set-up can be used to examine both reflection-free transparent conditions ('ONR test') and the effects of reflections ('WIN test', box p. 28). This makes it possible to differentiate between results for locations with a brightly lit background, such as noise barriers or glass balustrades, and those with a dimly lit background, such as windows and glass façades, where reflections influence the effect of markings.

**Hohenau flight tunnel ONR test**

Side view




Aerial view

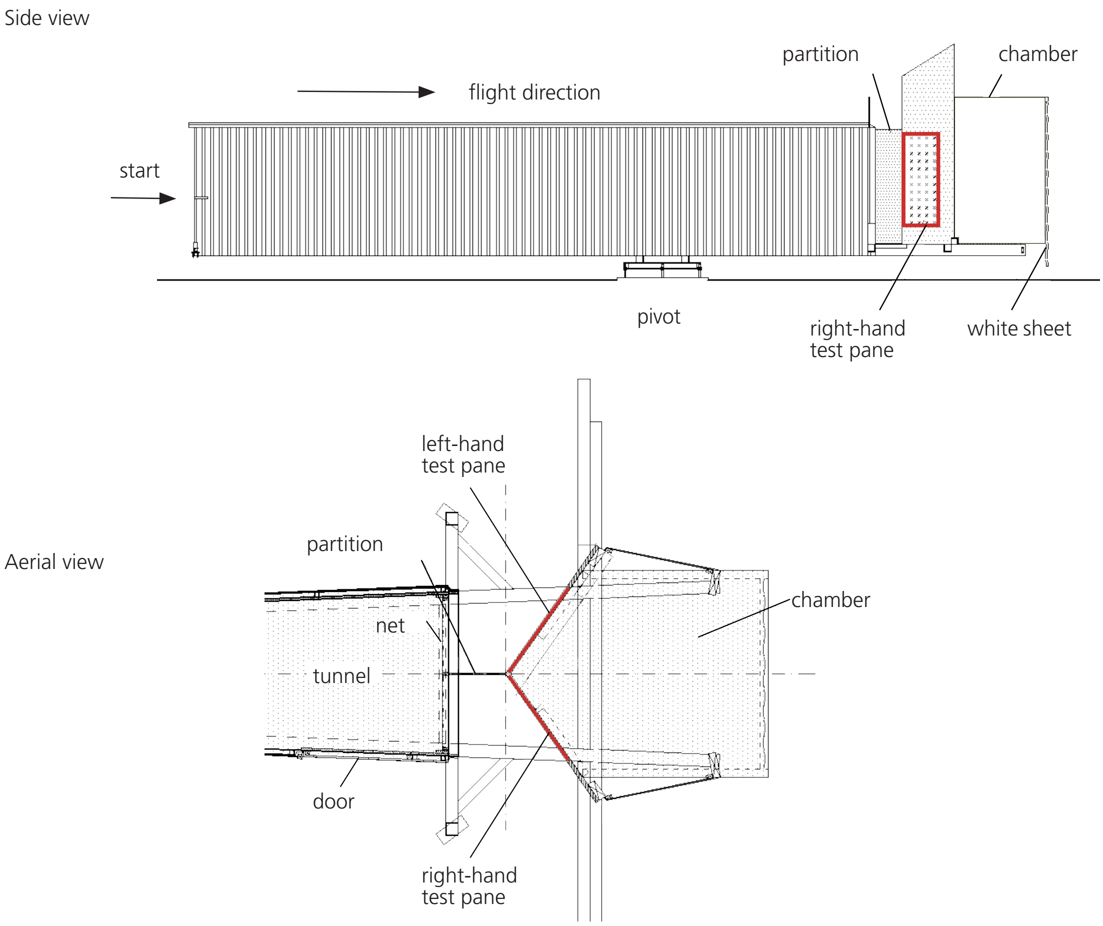



*Test apparatus to determine the effectiveness of markings in conditions of transparency (brightly lit background). The flight tunnel is mounted on a pivot and is adjusted to the position of the sun so that the sunlight always falls in the direction of the birds' flight. The sunlight is directed onto the two test panes (red) in parallel and symmetrically via two mirrors (mounted on the left and right sides). The test panes are at 90° to the flight axis of the birds, which are daylight-adapted at the time of the experiment.*

*The test bird (right hand) has been caught in one of 16 special nets and ringed, measured, and registered at the Hohenau-Ringelsdorf bird ringing station. The ring number is recorded again at the flight tunnel. The flight of the daylight-adapted birds, which lasts about three seconds, is recorded on video. Light meters automatically record the light conditions.*

*After every three test flights, the test panes are changed in a random order, so that all markings can be tested over an extended period of time and under different lighting conditions. On the way to the tunnel, the panes must be carried along a short 'jungle path'.*

**Hohenau flight tunnel WIN test**




*Test apparatus for integrating reflections (low-light background). The two test panes (red) are each turned 35° outwards (125° to the flight axis of the birds) and reflect the homogeneous surroundings like the side mirrors of a car. Reflections occur because of the chamber mounted behind the panes, where the light intensity corresponds to that of an indoor environment (cf. tab. 1, p. 9).*

### Development of tunnel tests to assess glass markings

**Daniel Klem, Muhlenberg College (USA)**

As early as the 1980s, D. Klem in the USA worked with a 'flight cage'[15], which used the flight of birds towards light to test the effect of various objects (strips of cloth, decoy birds of prey, strings of lights) and to quantitatively compare avoidance reactions. These tests generated numerous important findings, not least regarding the ineffectiveness of decoy birds.

**Hans-Willy Ley, Max Planck Institute for Ornithology, Radolfzell (Germany)**

In the 2000s, H. W. Ley worked at the Max Planck Institute in Radolfzell-Möggingen, Germany, in a former blackcap aviary from P. Berthold's famous experiments on bird migration. By converting the aviary into a flight tunnel, Ley was able to use it for research on the effectiveness of UV glass markings[16]. He worked with wild birds from the capture programme of the Radolfzell ornithological station. The end of the tunnel that opened towards the light was divided: on one side was an unmarked reference pane, on the other a marked test pane. A special net, which was invisible to birds, enabled all the birds to be intercepted before colliding with the pane and then released safely into the wild. The birds were dark-adapted, i.e. adapted to the weak light in the tunnel, and the test panes were artificially illuminated with an Osram Vitalux lamp.

**Martin Rössler, Hohenau-Ringelsdorf Biological Station (Austria)**

Ley's experience served as a basis for the work in Hohenau. Here, however, the birds are placed in the tunnel from the outside, while still adapted to daylight, to ensure that they will not be dazzled by the bright background. Due to the unnatural spectral distribution (colour composition) and flickering of the lamp, the artificial light was replaced by natural lighting. Unlike the previous studies, the Hohenau method of test flight evaluation is based on video recordings and not on one-off direct observations[17,18].

A crucial innovation came about as a result of preliminary tests in a fixed south-north oriented tunnel, where birds were sent through the tunnel into the open without encountering any obstacle (no test panes, no net). The tests instantly produced an astonishing finding: during morning flight tests, the vast majority of birds leaving the tunnel turned left (west); in the afternoon the majority turned right (east). This possible influence of the sun's position on the experiment was initially remedied by a tent-like extension to the tunnel, but it was necessary to improve the method for more in-depth investigations. Between 2004 and 2006, M. Rössler, W. Laube, C. Schauer and O. Schweinberger developed a tunnel construction in which the test panes, located 40 cm from the net and 30 cm from the end of the tunnel, are uniformly illuminated by lateral mirrors (illustration p. 26)[19]. The entire construction is placed on a pivot, allowing the tunnel to be turned to follow the sun. This ensures that the sunlight always falls in the same direction as the birds' flight, and that the shadows are symmetrical. Each year, approximately 2,500 wild birds are 'concentrated' on a test field of just over one square metre, under natural light conditions and with a natural background. The observation of each 'event' lasts only a few seconds. Until 2010, this flight tunnel was used exclusively for experiments with an unobstructed, transparent view onto a bright natural background. The procedure is laid out in the Austrian Normative Rule ONR 191040 and the method is therefore known in Europe as the 'ONR test'. The method was adopted in the USA in 2010 by C. Sheppard[20]; here birds fly towards an artificial (blue) background that is occasionally lit by strong sunlight.

In 2010, a methodological extension was carried out in Hohenau. To account for the reflections occurring on windows and façades, a chamber was set up behind the test panes (illustration p. 27), with light conditions similar to those of indoor rooms, only reflecting approx. 1 % of the daylight back onto the panes. The mirrors used for the ONR test (transparent conditions) were dismantled, and the panes were angled outwards by 35°. This means that they now face the homogeneous surrounding vegetation, are directly illuminated, and reflect the surroundings into the birds' line of sight like the side mirrors of a car. Currently, the majority of the results in Hohenau are gathered using this 'WIN method' (from WINdow).

[15] Klem, D. (1990): Collisions between birds and windows: mortality and prevention. *J. Field Ornithol.* 61: 120–128.

[16] Ley, H. W. (2006): Experimentelle Tests zur Wahrnehmbarkeit von UV-reflektierenden 'Vogelschutzgläsern' durch mitteleuropäische Singvögel. *Berichte zum Vogelschutz* 43: 87–91.

[17] Rössler, M. & T. Zuna-Kratky (2004): *Vermeidung von Vogelanprall an Glasflächen: Experimentelle Versuche zur Wirksamkeit verschiedener Glas-Markierungen bei Wildvögeln*. Wiener Umweltanwaltschaft.

[18] Rössler, M., E. Nemeth & A. Bruckner (2015): Glass pane markings to prevent bird-window collisions: less can be more. *Biologia* 70: 535–541.

[19] Rössler, M., W. Laube & P. Weihs (2009): *Avoiding bird collisions with glass surfaces. Experimental investigations of the efficacy of markings on glass panes under natural light conditions in Flight Tunnel II.* BOKU-Met Report 10.

[20] Sheppard, C. D. (2019): Evaluating the relative effectiveness of patterns on glass as deterrents of bird collisions with glass. *Global Ecology and Conservation* 20: e00795.

### 3.2.3 Hohenau evaluation scheme: the concept of highly effective markings

**Prerequisites and objectives**

Bird collisions with transparent or reflective glass can never be completely ruled out. However, to prevent as many casualties as possible and to ensure planning and legal certainty for all parties involved, it is important to be able to reliably measure the effectiveness of different deterrents. The methods described above allow replicable comparisons between all the tested markings under standardised conditions. They can then be ranked in terms of effectiveness. However, experiments cannot give accurate quantitative predictions of how many birds will, under fluctuating light conditions, actually recognise the marking and thus avoid collision.

The concept of highly effective markings aims to identify a statistically verified group of top- performing markings, involving different technical approaches. These markings can be expected to meet bird conservation requirements under different daylight conditions in different locations.

**Classification scheme**

The Hohenau-Ringelsdorf Biological Station makes its recommendations according to a widely accepted classification scheme, which was internationally agreed upon by experts in 2008 and forms the basis for the Austrian Normative Rule ONR 191040. The test results are divided into four categories, with the following values applying to both the transparency test (ONR) and the reflection test (WIN). A full recommendation is awarded for category A ('**highly effective**'). The threshold for category A is a ratio of 10:90. This means that at least 90 % of the birds fly towards the unmarked reference pane, proving that the markings are readily perceived by birds. Where birds fly towards test panes in >10-20 % of test flights, the Hohenau classification ranks the marking '**somewhat effective**'. These are not recommended per se, as a strong reduction in effectiveness cannot be ruled out under different conditions, e.g. under poor light conditions. If birds fly towards the marked pane in more than 20 % of test flights, the rating is '**barely effective**'. This category includes markings that can be shown to have an effect but should not be regarded as true bird protection. In cases where birds

*Table 2: Hohenau classification scheme for tested markings based on choice tests with marked test panes and unmarked reference panes. For statistical reasons, markings can generally be recommended if birds fly towards them in up to 12 % of tests.*

| | Bird flights towards the test panes (%) | Level of recommendation |
|---|---|---|
| **Category A** **Highly effective** | 0-10 | Fully recommended |
| **Category B** **Somewhat effective** | >10-20 | Generally not recommended |
| **Category C** **Barely effective** | >20-42 | Not recommended |
| **Category D** **Not effective** | >42 | Not recommended |

*The window panes of this lakeside restaurant at the Neusiedler See National Park (Austria) were printed with thin black lines on the outside.*

fly towards test panes in 42 % or more of test flights (ratio of 42:58), markings are defined as '**not effective**', because it is impossible to say with any statistical certainty whether the marking influences birds' choice of direction.

It is important to note that markings found to be highly effective on transparent surfaces are not necessarily the most suitable on reflective surfaces. The test method must fit the area of application. For transparent glass surfaces (noise barriers, glass balustrades, etc.) the results of the ONR tests apply, whereas for reflective glass surfaces (windows and façades) the results of the WIN tests apply.

## 3.2.4 Criteria for highly effective bird protection markings

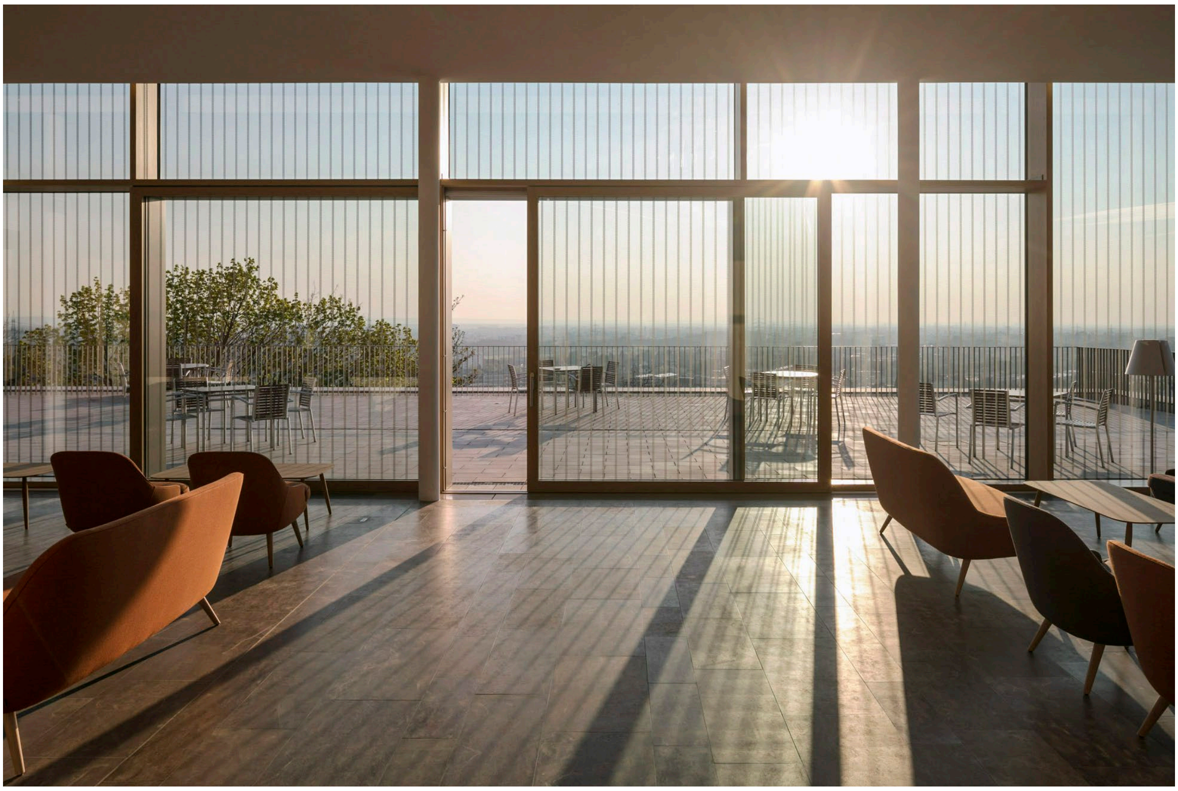
Standardised investigation into the effectiveness of glass markings has yielded some fundamental insights. The question here is: which markings can flying birds recognise as obstacles? The key considerations are size, spacing and contrast, and possibly also the shape of the marking elements.

**Size of the markings**

The important factors here are the optical resolution of the avian eye and the 'stopping distance', i.e., the distance to the obstacle, as well as the bird's speed and reaction time. Horizontal stripes with a good level of contrast can be perceived sufficiently well if they are 3 mm or wider; for vertical stripes, the tests showed 5 mm to be the minimum width that was effective. For dots, the minimum diameter is 9 mm. The lower the contrast, the bigger the stripes or dots must be.

**Surprising findings on the permissible distance between dots/stripes**

When it comes to the spacing between markings, it is not the birds' perception that counts, but rather their behavioural reactions – whether something the bird sees actually causes it to change direction. When danger is detected, rapid unconscious reactions occur. The sensory impressions of alarm are transmitted directly to the cerebellum via neuronal circuits in fractions of a second. It has been shown that the critical distance between markings is not an absolute quantity, but rather depends on the orientation and the shape of the obstacles detected. The maximum spacing (distance between edges) for horizontal stripes to be highly effective is 50 mm, compared to 100 mm for vertical stripes and 90 mm for dots, both horizontally and vertically. Surprisingly, larger vertical distances can be effective between dots than between horizontal stripes. This significantly reduces the area taken up by the markings. However, markings cannot be scaled, and



*During the conversion of the Michaelsberg Abbey, a listed building, caspar.architects included highly effective anti-collision markings as a design element.*

*The bird protection pattern used in this noise barrier by Treusch architecture in Theodor-Körner-Hof in Vienna deliberately emphasises its three-dimensional structure.*

dense grids of small dots show little or no effect. For example, a grid of 3 mm dots with a grid spacing of 14 mm is not recognised as an obstacle.

**Marking colour, contrast, and coverage**

As mentioned, the critical sizes and spacings apply to high-contrast markings, such as those using deep black. The darkest grey is significantly less effective than black and the lightest grey significantly less effective than white. The more reflective a glass pane is, the more difficult it is to create strong contrasts. However, the extreme brightness of metallic reflective markings can produce particularly strong contrasts and thus achieve high effectiveness even at <1 % of total surface coverage. Lower-contrast markings require a higher degree of coverage. Semi-transparent, frosted glass markings require at least 11 % coverage (cf. p. 38, no. 2), and semi-transparent films at least 20 % (cf. p. 37, nos. 8 & 10).

### 3.2.5 Current developments in bird-friendly glass for windows and building façades

**Industry and ornithologists are working together**

It is impossible to reduce the risk of bird collisions without altering the visual properties of glass. However, developments are moving towards far more discreet markings. While the first experiments were carried out with materials such as adhesive strips, films and spray paint, markings are now being created in the laboratories of glass manufacturers and research institutes, and progress is being made on special materials and coatings. At present, research in physics and process engineering and collaboration with professional ornithologists is generating rapid progress. Every year sees new ideas and concepts, as well as gradual improvements to established markings. So the findings presented here only capture the current state of knowledge. All the markings shown here were tested against a low-light background (WIN test, section 3.2.2) and are therefore not automatically suitable for situations where the background is brighty lit, making the glass transparent.

**Metallic markings and one-way mirror patterning – very high contrast**

The ideas of a team from the UK-based NSG Pilkington Group inspired a major innovation in 2013. Metallic coatings cause very bright, light-intense

*The glass industry is taking a growing interest in bird protection and is working with ornithological researchers to develop discreet and elegant markings. While detached houses frequently have high collision rates, there is often a high acceptance of markings in these cases. This highly effective dot grid was applied after construction.*

reflections on less reflective glass and can therefore create very strong contrasts. NSG Pilkington developed striped patterns made of extremely thin metallic coatings on the outside of the panes, creating a one-way mirror effect. Viewed from the outside, the stripes appear in high contrast; from the inside, the pattern is only slightly visible. A variant launched in 2021 has been classified as highly effective.

Tried and tested patterns such as vertical 5mm-wide stripes can also be produced with opaque metallic coatings and can be classified as highly effective.

*Bird's-eye view in the test tunnel. Pilkington AviSafe™ exterior view: highly effective as protection against bird collision, barely visible from the interior (left: test pane, right: reference pane).*

*Arnold Glas Ornilux® design lines 5/95: highly effective metal marking with classic striped pattern (left: test pane, right: reference pane).*

**Dot grids – unexpectedly effective**

While grid arrangements of dots have been recommended for years in the USA, there was no systematic investigation of dot grids in Europe until 2017. Paradoxically, dots tend to allow wider spacing than stripes, a phenomenon that cannot be explained at present. Once again, the right choice of size, spacing and contrast is crucial here. Dots should be 9-12 mm in diameter and 90-100 mm apart (distance between centre points). Grid prints consisting of small dots (1-3 mm, up to 30 % surface coverage), which are used as sun protection, have been proposed several times as bird protection. These, however, are not effective in preventing collisions.

*Eastman Saflex® FlySafe™ SEEN shiny 9/90: metallic dots, 9 mm in diameter and 90 mm apart: highly effective and – due to high reflectance – also suitable for surface 2 (left: test pane, right: reference pane).*

*Despite the small spacing between dots, this dot grid is ineffective: a dense grid of black dots with 3 mm diameter was not recognised by birds even on surface 1 (left: test pane, right: reference pane).*

*This grid of 9 mm metallic dots at 90 mm intervals is laminated onto the inside of a pane of insulating glass and yet highly effective. In contrast, black markings have only proven effective on the outside of façade glass due to reflections.*

**Towards highly effective transparent markings**
A major focus at present is the development of largely transparent markings. Researchers are trying to apply the current understanding of how flying birds perceive contrast, and to create reflections in optimal spectral ranges using complex coating methods. Individual prototypes from the Fraunhofer Institute for Solar Energy Systems (ISE) are already proving highly effective. However, high transparency does not necessarily equate to invisibility, and researchers are still looking for more aesthetically satisfying solutions.

**UV markings – still not recommended**
Beyond printing and applying films with opaque patterns, developers have been building on the idea of 'invisible' UV markings since the early 2000s. This approach is based on the assumption that birds can perceive UV light, whereas humans cannot – an apparently perfect solution to the problem. However, the notion that 'birds can see UV' is an oversimplification, for the following reasons:

1) The intensity of UV radiation depends on the sun's elevation and cloud density. In bad weather, in overshadowed areas, in forests and in dense vegetation, the intensity drops sharply.

2) Only four groups of bird species – ostriches, gulls, parrots, and songbirds (except corvids) – have specific UV sensors[21].

In the Hohenau flight tunnel tests incorporating reflections, almost all the transparent UV markings proved to be either completely ineffective or barely effective (tab. 3). Out of seven markings which tested as ineffective, five were UV markings. Out of 40 tested markings, UV markings ranked between 31 and 40. These markings tended to perform slightly better when the test was set up with a brightly lit background and did not incorporate reflections. From 2016 to 2020 the Bavarian Association for Bird Protection (LBV) conducted a field study to test and evaluate four different UV markings in real-life situations. A significant reduction in bird collisions was observed in individual cases, but a significantly higher proportion of tests found that these markings had little or no effect. In the 453 fatalities registered, 26 % of the birds collided with a UV-marked pane.

*A marking currently being developed by the Fraunhofer Institute for Solar Energy Systems (ISE), with transparent stripes on surface 1, proved to be highly effective (left: test pane, right: reference pane).*

*Table 3: Results of choice tests (WIN test) of UV markings in the flight tunnel of the Hohenau-Ringelsdorf Biological Station.*

| Test marking | Flights towards test pane | Flights towards reference pane | Result |
|---|---|---|---|
| Ornilux Mikado® [22] | 56 % | 44 % | Not effective |
| Kolbe Bird Sticker® bird silhouettes, 21.7 % coverage [23] | 53 % | 47 % | Not effective |
| Kolbe Bird Pen®, 21.6 % coverage [24] | 36 % | 64 % | Barely effective* |

* *Surprisingly, no increased reflection was measured in the UV range[24].*

[21] Martin, G. R. (2017): *The sensory ecology of birds*.Oxford University Press.

[22] Rössler, M. (2012): Mikado®: https://wua-wien.at/images/stories/publikationen/vogelanprall-ornilux-mikado.pdf (28 September 2022).

[23] Rössler, M. (2018): birdsticker®: https://wua-wien.at/images/stories/publikationen/pruefbericht-birdsticker-2018.pdf (28 September 2022).

[24] Rössler, M. (2015): birdpen®: https://wua-wien.at/images/stories/publikationen/pruefbericht-birdpen-2015.pdf (28 September 2022).

*Stickers of the silhouettes of birds of prey usually indicate that collision is a known issue in this location. However, they are not effective and should not be used, as collisions will continue to occur in direct proximity to the stickers. Instead, tested markings that mark the entire glass surface should be used.*

## 3.2.6 Markings tested in the flight tunnel

The following pages show a selection of the most important test results from the Hohenau flight tunnel. Here, for the first time, a distinction is made between markings for transparent glass against a bright background, such as noise barriers (ONR test, pp. 36-37), and markings for use in front of low-light backgrounds such as windows and façades (WIN test, pp. 38-41). The colour refers to the four classifications in the Hohenau evaluation scheme (section 3.2.3). The percentage indicates the proportion of birds that flew towards the test pane in the choice test – the smaller this number is, the better the pattern is recognised by the birds. This determines its ranking.

Even small modifications of a pattern in terms of design, scale, colour, or material can influence its effectiveness. The degree of external reflection (reflectance) must also be considered, especially in the WIN test. The test result here is valid only up to the specified reflectance of the test pane in question.

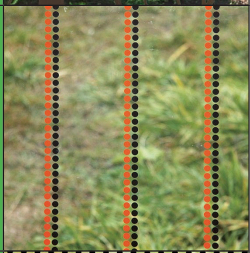
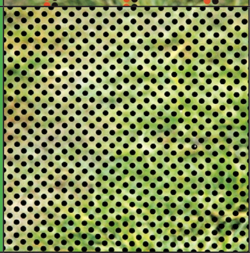
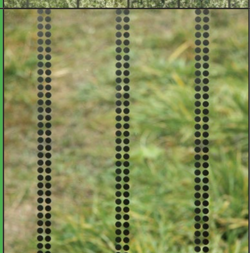
**Abbreviations**

CR: Covarage Rate, percentage of area covered by the markings
ER: External reflectance of the entire test pane
DM: Diameter
ED: Distance between edges of markings
CD: Distance between centres of markings
GBP: Gap between panes
LSG: laminated safety glass
n/a: not available

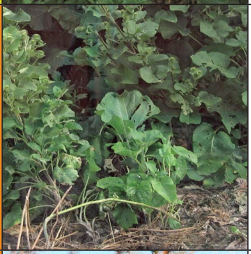
Surface indicates where a coating is applied, starting on the outside and moving inwards. Surface 1 is the outside of the pane, surface 2 is the inside of a single pane or of the outer pane of an insulating glass unit, surface 3 is the front side of the second pane of an insulating glass unit, and so on.

**Test reports** can be found on the website of the Vienna Ombuds Office for Environmental Protection (Wiener Umweltanwaltschaft) at wua-wien.at/publikationen.

## Patterns tested for noise barriers and glass balustrades (ONR test, transparency)

| No. | Flights towards test pane | Image | Description |
|---|---|---|---|
| 1 | 2 % |  | Name/description: ZOOLEX branch pattern / Gasperlmair<br>Material/colour: Film RAL 6014 yellow olive, 25 % transparency<br>Surface: 1<br>CR: 20-25 % |
| 2 | 2 % |  | Name/description: Eckelt 4Bird V3066 vertical rows of dots<br>Dimensions: DM 8 mm, ED between rows of dots 100 mm<br>Material/colour: Screen printing black-orange<br>Surface: 1<br>CR: 9 % |
| 3 | 3 % |  | Name/description: Eckelt Litex 540 diagonal black dot grid<br>Dimensions: DM 7.5 mm, diagonal CD 12.7 mm<br>Material/colour: Screen printing black<br>Surface: 1<br>CR: 27 % |
| 4 | 3 % |  | Name/description: Vertical black stripes<br>Dimensions: 5 mm wide, ED 95 mm<br>Material/colour: Black print on polycarbonate<br>Surface: 1<br>CR: 5 % |
| 5 | 5 % |  | Name/description: Eckelt 4Bird V3067 vertical rows of dots<br>Dimensions: DM 8 mm, ED between rows of dots 100 mm<br>Material/colour: Screen printing black<br>Surface: 1<br>CR: 9 % |
| 6 | 5 % |  | Name/description: Horizontal black stripes<br>Dimensions: 3 mm wide, ED 47 mm<br>Material/colour: Black print on polycarbonate<br>Surface: 1<br>CR: 6 % |
| 7 | 6 % |  | Name/description: Vertical orange stripes<br>Dimensions: 5 mm wide, ED 100 mm<br>Material/colour: Orange spray paint Duplicolor Platinum RAL 2009<br>Surface: 1<br>CR: 4.8 % |

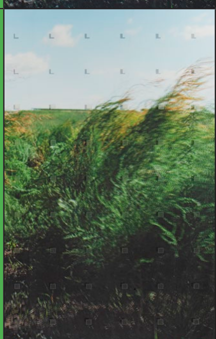
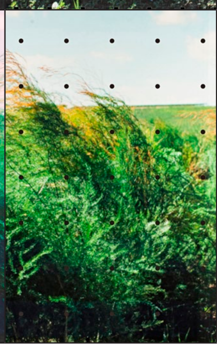
| Category A, Highly effective | Category B, Somewhat effective | Category C, Barely effective | Category D, Not effective |
|---|---|---|---|

| No. | Flights towards test pane | Image | Description |
|---|---|---|---|
| 8 | 6 % |  | Name/description: Glasdecor 25<br>Dimensions: Stripes of varying width 15-40 mm, horizontal distance <100 mm<br>Material/colour: Adhesive film ORACAL Etched Glass Cal 8510, matt, translucent<br>Surface: 1<br>CR: 25 % |
| 9 | 6 % |  | Name/description: Saflex® FlySafe™ 3D SEEN shiny 9/90 dot grid 9/90<br>Dimensions: DM 9 mm, CD 90 mm<br>Material/colour: Aluminium<br>Surface: 2<br>CR: 0.8 %<br>Structure: LSG 44.2 |
| 10 | 10 % |  | Name/description: ABC Bird Tape double vertical stripes<br>Dimensions: 20 mm wide stripes, distance between stripes alternately 5 mm and 100 mm<br>Material/colour: Translucent ABC Bird Tape<br>Surface: 1<br>CR: 22.8 % |
| 11 | 15 % |  | Name/description: White dot grid<br>Dimensions: DM 18 mm, CD 82 mm<br>Material/colour: White screen printing<br>Surface: 1<br>CR: 3.8 % |
| 12 | 35 % |  | Name/description: Plexiglas Soundstop®<br>Dimensions: 15 mm thick<br>Material/colour: Smoky Brown, tinted acrylic glass |
| 13 | 37 % |  | Name/description: Ornilux Mikado (Ornilux Neutralux 1.1 - June 2011)<br>Material/colour: Coatings on interior of insulating glass which, according to the manufacturer, reflect and absorb UV radiation |
| 14 | 54 % |  | Name/description: Birdpen®<br>Material/colour: A marker pen is used to apply substances to the glass which, according to the manufacturer, create contrasts in the UV range<br>Surface: 1<br>CR: approx. 50 % |

## Patterns tested for windows and façades (WIN test, reflections)

| No. | Flights towards test pane | Seen from outside (reflection of the surroundings) | Seen from inside | Description | Notes |
|---|---|---|---|---|---|
| 1 | 4 % |  |  | Name/description: ZOOLEX branch pattern / Gasperlmair<br>Type: Non-geometric shape<br>Dimensions: Variable<br>Material/colour: Digital print, RAL 6014 yellow-olive<br>Surface: 1<br>CR: 20-25 %<br>Structure: Monolithic float glass, 6 mm<br>Functional coating: none<br>ER: 8 %<br>Test year: 2020 | This marking was developed for use in zoos. |
| 2 | 6 % |  |  | Name/description: AGC Interpane, etched effect<br>Type: Vertical broken double stripes<br>Dimensions: Rectangles, 8 × 30 mm<br>Material/colour: Etched-effect screen printing<br>Surface: 1<br>CR: 11 %<br>Structure: LSG 66.2<br>Functional coating: none<br>ER: 8 %<br>Test year: 2019 | Two versions of this screen-printed marking were tested (cf. no.13). This etched-effect version is significantly more effective than the other version. |
| 3 | 6 % |  |  | Name/description: Saflex® FlySafe™ 3D SEEN shiny 9/90 ISO<br>Type: Dot grid<br>Dimensions: DM 9 mm, CD 90 mm<br>Material/colour: Multilayer aluminium<br>Surface: 2<br>CR: 0.8 %<br>Structure: Insulating glass LSG 44.2 / GBP 16 mm / 4 mm float<br>Functional coating: Low-E (ClimaGuard Premium, surface 4)<br>ER: 12 %<br>Test year: 2020 | Saflex® markings have been tested several times, here with a low-E coating on insulating glass. The marking was first tested in 2019 as 'SEEN elements' (nos. 6 and 7). |
| 4 | 8 % |  |  | Name/description: Ornilux® design lines 5/95 - Decochrome<br>Type: Vertical stripes<br>Dimensions: 5 mm wide, ED 95 mm<br>Material/colour: Decochrome<br>Surface: 1<br>CR: 5 %<br>Structure: LSG 66.2<br>Functional coating: none<br>ER: n/a<br>Test year: 2020<br>Test report: Vienna Ombuds Office for Environmental Protection (WUA) | Ornilux® design refers to visible markings with metallic surfaces.<br>Not to be confused with UV variants under the name Ornilux®. |
| 5 | 9 % |  |  | Name/description: AviSafe™ AS/h (hard-edge) laminated 70/40<br>Type: Vertical stripes<br>Dimensions: 40 mm wide stripes, distance 60 mm, blurred edges<br>Material/colour: Semi-reflective coating (transparent from inside), metallic reflective<br>Surface: 1<br>CR: n/a<br>Structure: Insulating glass LSG 64.2//4 mm float<br>Functional coating: Solar Control 70/40, surface 4<br>ER: n/a<br>Test year: 2021 | AviSafe™ markings are reflective on the outside and are transparent and only faintly visible from the inside. |

| Category A, Highly effective | Category B, Somewhat effective | Category C, Barely effective | Category D, Not effective |
|---|---|---|---|

| No. | Flights towards test pane | Seen from outside (reflection of the surroundings) | Seen from inside | Description | Notes |
|---|---|---|---|---|---|
| 6 | 9 % |  |  | Name/description: SEEN shiny 9/90 (later Saflex®)<br>Type: Dot grid<br>Dimensions: DM 9 mm, CD 90 mm<br>Material/colour: Multilayer aluminium<br>Surface: 2<br>CR: 0.8 %<br>Structure: LSG 44.2<br>Functional coating: none<br>ER: 8 %<br>Test year: 2019<br>Test report: WUA | 'SEEN shiny' elements have shiny concave surfaces with very strong light reflection and are also highly effective on surface 2. Suitable for retrofitting on surface 1. |
| 7 | 9 % |  |  | Name/description: SEEN matt 9/90<br>Type: Dot grid<br>Dimensions: DM 9 mm, CD 90 mm<br>Material/colour: Aluminium coating<br>Surface: 2<br>CR: 0.8 %<br>Structure: LSG 44.2<br>Functional coating: none<br>ER: 8 %<br>Test year: 2019<br>Test report: WUA | 'SEEN matt' elements have matt, flat surfaces that reflect light evenly. Suitable for retrofitting on surface 1. |
| 8 | 10 % |  |  | Name/description: Saflex® FlySafe™ 3D SEEN shiny 9/90<br>Type: Dot grid<br>Dimensions: DM 9 mm, CD 90 mm<br>Material/colour: Multilayer aluminium<br>Surface: 2<br>CR: 0.8 %<br>Structure: LSG 44.2<br>Functional coating: St. Gobain COOL-LITE® ST167<br>ER: 19 %<br>Test year: 2021 | This test case refers to the Saflex® 9/90 dot grid in LSG with 19 % external reflection (cf. no. 6). |
| 9 | 10 % |  |  | Name/description: SEDAK squares 12 mm black<br>Type: Dot grid<br>Dimensions: Squares with 12 mm sides, CD 90 mm<br>Material/colour: Screen printing, RAL 9005<br>Surface: 1<br>CR: 1.8 %<br>Structure: LSG 44.2<br>Functional coating: none<br>ER: 8 %<br>Test year: 2019<br>Test report: WUA | Black screen-printed and film patterns had previously only been tested on surface 1 (cf. nos. 10 and 17). |
| 10 | 11 % |  |  | Name/description: Anthracite 10/100 dot grid, no specific manufacturer<br>Type: Dot grid<br>Dimensions: 10 mm DM dots, CD 100 mm<br>Material/colour: Plotted adhesive foil, RAL 7016<br>Surface: 1<br>CR: 0.8 %<br>Structure: Monolithic float glass, 4 mm<br>Functional coating: none<br>ER: 8 %<br>Test year: 2018 | Suitable for retrofitting. |

| No. | Flights towards test pane | Seen from outside (reflection of the surroundings) | Seen from inside | Description | Notes |
|---|---|---|---|---|---|
| 11 | 14 % |  |  | Name/description: Saflex® FlySafe™ SEEN shiny 3/50<br>Type: Dot grid<br>Dimensions: DM 3 mm, CD 50 mm<br>Material/colour: Multilayer aluminium<br>Surface: 2<br>CR: 0.3 %<br>Structure: LSG 44.2<br>Functional coating: none<br>ER: 12 %<br>Test year: 2020 | Metallic dots with 3 mm DM are less effective than with 9 mm DM (nos. 3, 6 and 7). |
| 12 | 16 % |  |  | Name/description: Ornilux® design dart 9/90 - Decochrome<br>Type: Dot grid<br>Dimensions: pierced, cockade-like dots, outer ring 2 mm, inner circle 3 mm DM, grid spacing: 90 mm<br>Material/colour: Decochrome<br>Surface: 1<br>CR: 0.4 %<br>Structure: LSG 66.2<br>Functional coating: none<br>ER: n/a<br>Test year: 2020<br>Test report: WUA | Pierced metallic circles ('cockades') are less effective than metallic stripe pattern no. 4. |
| 13 | 16 % |  |  | Name/description: AGC Interpane Ipasol grey / Ipasol bright<br>Type: Vertical broken double stripes<br>Dimensions: Rectangles, 8 × 30 mm<br>Material/colour: Screen printing Ipasol grey / Ipasol bright<br>Surface: 1<br>CR: 11 %<br>Structure: LSG 66.2<br>Functional coating: none<br>ER: 8 %<br>Test year: 2020 | Transparent version of etched-effect pattern (no. 2). |
| 14 | 32 % |  |  | Name/description: Diagonal dot grid 5 mm etched<br>Type: Diagonal dot grid<br>Dimensions: DM 5 mm, diagonal CD 35 mm<br>Material/colour: Etched<br>Surface: 1<br>CR: 1.6 %<br>Structure: Insulating glass 6 mm float / GBP: 16 mm / 6 mm float<br>Functional coating: Low-E on surface 3<br>ER: n/a<br>Test year: 2021 | Etched dot grid with dot DM of 5 mm is not very effective (contrast too low and DM too small). |
| 15 | 45 % |  |  | Name/description: Vertical rows of dots 3 mm black<br>Type: Vertical row of dots<br>Dimensions: DM 3 mm, CD within row 6 mm, between rows 38 mm<br>Material/colour: Black screen printing<br>Surface: 2<br>CR: 3.1 %<br>Structure: Insulating glass 6 mm float / GBP: 16 mm / 6 mm float<br>Functional coating: Low-E on surface 3<br>ER: n/a<br>Test year: 2021 | Rows of dots with dot DM of 3 mm on surface 2 are ineffective (pattern too fine). |

| No. | Flights towards test pane | Seen from outside (reflection of the surroundings) | Seen from inside | Description | Notes |
|---|---|---|---|---|---|
| 16 | 47 % |  |  | Name/description: Kolbe birdsticker® silhouettes<br>Type: Bird silhouettes 15 pcs.<br>Dimensions: 94 cm2/silhouette.<br>Material/colour: Transparent, UV reflective<br>Surface: 1<br>CR: 21.7 %<br>Structure: Monolithic float glass, 4 mm<br>Functional coating: none<br>ER: 8 %<br>Test year: 2017<br>Test report: WUA | Ineffective UV marking. |
| 17 | 48 % |  |  | Name/description: Anthracite 3/14 dot grid<br>Type: Dot grid<br>Dimensions: Dots 3 mm DM, CD 14 mm<br>Material/colour: Plotted adhesive foil, RAL 7016<br>Surface: 1<br>CR: 3.6 %<br>Structure: Monolithic float glass, 4 mm<br>Functional coating: none<br>ER: 8 %<br>Test year: 2018<br>Test report: WUA | Black dot grid with dot DM of 3 mm ineffective on surface 1 (pattern too fine; cf. also rows of dots in no. 15). |

# 3.3 Retrofitting

**Retrofitting is more expensive than building with bird-friendly glass**
The standard measures available for existing problematic glass surfaces are films with printed patterns, or pattern elements stuck on by means of a carrier film. These films make transparent and reflective glass surfaces visible to birds.

However, compared to bird-friendly glass products (e.g. printed glass, translucent glass, textured glass), such retrofitting measures are less durable and need to be renewed regularly. This means that most retrofitting measures are more expensive in the long run, compared to bird protection measures that are integrated during the planning phase. Another important consideration is that the use of films generates large amounts of waste.

Another option for retrofitting glass surfaces to prevent bird collisions is the use of fine-meshed structures such as wire netting, wooden lattices, cords, nets, etc.

**Always mark reflective surfaces on the outside!**
For all retrofitting measures on windows and other reflective glass surfaces, the marking must always be applied to the outside. In the case of free-standing panes where transparency (as opposed to reflection) is the relevant risk factor, the marking can be applied to whichever side is most convenient.

Extensive retrofitting of bird protection measures is usually carried out by specialist companies. Often additional costs are incurred because cherry pickers or scaffolding are required.

**Films printed with bird protection markings**
Transparent films printed with bird protection markings are applied to the entire surface of the glass. The films must be suitable for outdoor use, and they must be mounted on the outside to disrupt reflections on the outer glass surface. Care must be taken to ensure that the desired patterns meet the specifications for highly effective markings (section 3.2.4).

Various special films (burglary protection, shatter protection, etc.) can be printed with bird protection markings, provided these films are highly transparent.

With printed films, attention must be paid to the lightfastness (UV resistance) and opacity of the print. Only fully opaque colours guarantee the contrast necessary for reliable collision prevention. According to the manufacturer, these films have a service life of 5 to 15 years, after which they may need to be renewed. Professional sealing of the film edges can increase durability.

**Plotted film patterns**
Another way to retrospectively mark surfaces is to apply plotted patterns from a backing film. Since the films used for this purpose are generally made of solid-coloured plastic material, there is less risk of fading than with printed films. The patterns are cut to size on the plotter and can be tailored to the customer's wishes. A disadvantage compared to films applied over the entire surface is a greater susceptibility to damage and weathering. According to the manufacturers, these patterns typically last 5 to 15 years.

*Printed films are applied to the entire surface of the glass.*

*When plotted film patterns are applied, only the pattern elements themselves adhere to the glass.*

*To prevent bird collisions at the new Bauhaus Museum in Dessau, Germany, more than 2700m² of glass façade were retrofitted with a plotted line pattern.*

**Danger of thermal stress glass breakage after retrofitting with adhesive film**

Thermal stress glass breakage is caused by large temperature differences on a glass surface.

In strong sunlight, the surface of a pane of glass heats up. If large areas of the pane are coated with dark colours or other absorbent materials, these usually heat up more than the rest of the surface. If the temperature difference is more than 40 Kelvin, thermally induced glass breakage can occur on non-toughened glass. Tempered glass (safety glass) and partially tempered glass have a much higher resistance to thermal stress. This glass can easily withstand increased thermal loads caused by films, paint, or etching without any increase in the risk of breakage.

Most of the bird protection patterns tested are extremely small. These patterns do not generate any extensive heating of portions of the panes and can generally be used safely either as a plotted film pattern or as a printed film.

There is an exception, however: the combination of sun protection film with a printed bird protection pattern. The addition of sun protection tinting can lead to increased temperature differences between the individual panes and thus to a higher risk of thermal stress breakage, especially in the case of sensitive triple glazing.

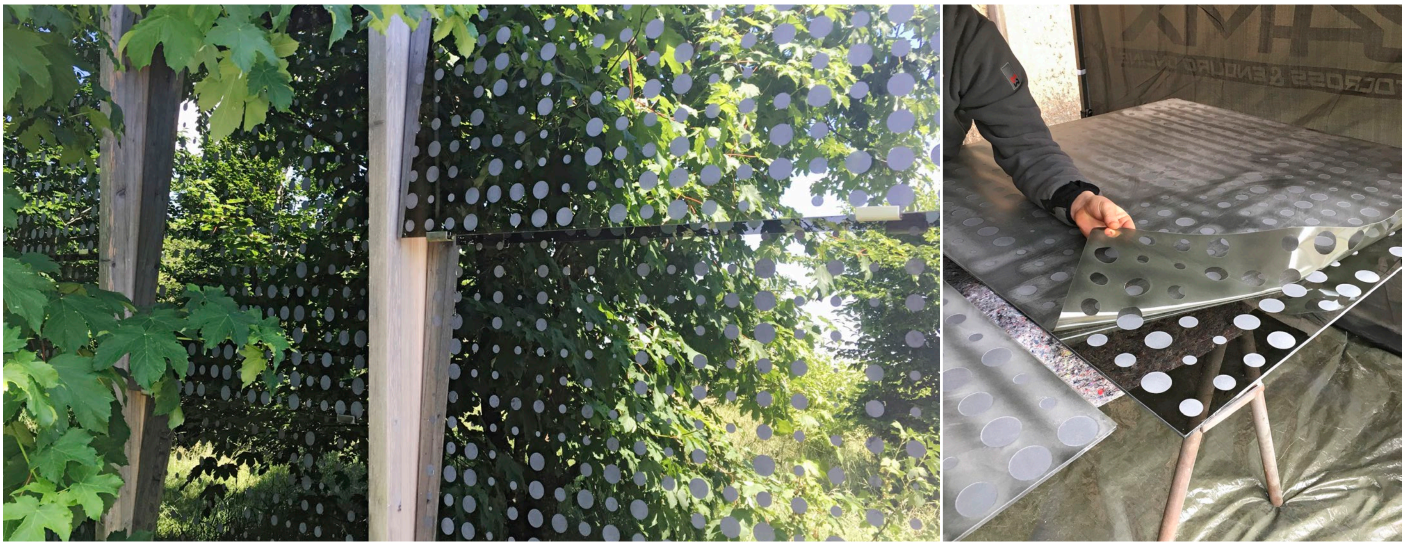
To prevent reflections and potential heating effects, retrofitted adhesive bird protection markings must be applied to the outside of the glass pane. In this case, constant ventilation ensures cooling, whereas strong sunlight on the inside can quickly lead to heat accumulation and thus to glass breakage.

**Sandblasting and satin finishing**

To prevent bird collisions, sandblasting or satin finishing can be employed to give the glass panes a matt surface. Glass treated in this way has non-transparent and non-reflective properties and can be used, for example, for façades or balcony balustrades.

In the sandblasting process, the abrasive effect of sand sprayed onto the glass surface with compressed air turns a smooth, mirror-like surface into a rough, diffusely reflective one. In satin finishing, a chemical process is used to frost the surface of the glass.

These processes are suitable for on-site retrofitting, and can be used either to modify entire panes of glass or to mark individual areas.



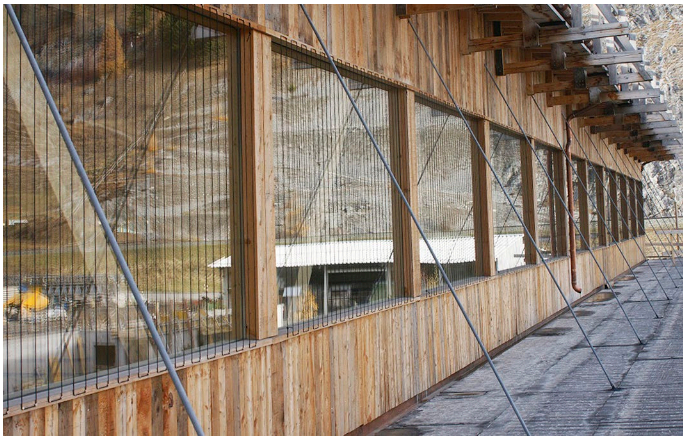
*This façade in Scharnstein, Austria was improved by sandblasting. To prevent bird collisions, the individual highly reflective glass panes were removed and then modified on site by a process of partial sandblasting ('punch card' dot grid in varying diameters).*

**Steel mesh**
Steel mesh, as used for façade protection and green walls, is suitable for retrofitting and permanent installation. When using it to protect against bird collision, it is important to ensure that the cable thickness and mesh size comply with the specifications for highly effective bird protection designs. Cable thickness should be at least 3 mm and the mesh should not be too large (max. 7×7 cm when installed diagonally or max. 10 cm at its widest point).

**Synthetic mesh**
Synthetic mesh should be considered a temporary stopgap. As with steel mesh, the material must be at least 3 mm thick, with a maximum mesh size of 10 cm. High-contrast colours must be used. The netting must be tightly stretched and fitted against the window, otherwise birds can get caught in the meshes.

**Cords**
A simple and inexpensive way to make glass surfaces visible to birds is to stretch cords or strings across them. Cords at least 3 mm thick and 10 cm apart should be fastened vertically in front of the pane. They should be made of weatherproof material and the colour must contrast well with the background. Black, white, or orange/red cords are most readily recognised as obstacles by birds. Such

*Steel mesh, often used to grow plants on buildings, can also be used for bird protection if the cables are thick enough. For the Engeldamm Passive House (PHED) in Berlin, designed by scarchtitekten joerg springer/robert mieth, this form of façade was planned from the outset. Depending on the nature of the façade, however, this type of netting can also be retrofitted.*



*After repeated bird collisions with the reflective windows of a factory building in S-chanf, Switzerland, black nylon cords were put up at 8-10 cm intervals. No further bird collisions were recorded after the retrofitting.*

cord curtains are simple to make, and the size and method of attachment can easily be adapted to fit any circumstances. In North America they can be bought as a ready-made product known as Acopian Bird Savers.

**Adhesive dots**

In private settings and for smaller windows, an effective dot pattern can easily be created with commercially available adhesive dots. These should be black, white, orange or red, with a diameter of 1.2 to 2 cm, and should be stuck on the outside of the pane at a maximum spacing of 9 cm. This is not suitable for larger buildings and new construction projects, however; in these cases it is essential to apply the measures described in sections 3.1 and 3.2.

**Artistic retrofitting**

Sometimes windows offer an opportunity for unique and decorative design. For example, waterproof window paints or pens can be used to apply creative bird protection patterns. Designs should be black, white, orange, or red to ensure good visibility for birds. Other techniques such as stencils, spray paints, or decorative window stickers can also be used.

When it comes to choosing the motifs, there are no limits to the imagination; the only stipulation is that the window surface should be fully marked, with no gaps higher than 5 cm or wider than 10 cm.

It is also important to note that these creative designs must always be applied to the outside of reflective window panes; here the materials used must be waterproof and weatherproof. Markings should only be placed on the inside if the pane is reflection-free and entirely transparent.

*In this creative marking, the motifs are distributed over the entire surface without leaving any large gaps. Despite this, the view from inside is not greatly restricted and the windows continue to provide light.*

*The strong reflections of vegetation on the windows at the front of the secondary school in Beromünster, Switzerland, led to frequent bird collisions. Silhouettes of birds of prey were installed around 20 years ago, but these did not improve the situation. In a subsequent school project, young people designed a creative window marking that meets the requirements for effective bird protection.*

# 4 Unsuitable measures

It is still common to find erroneous claims about the properties of certain markings and recommendations for measures that have been proven to be inadequate. As a consequence there are still products on the market that are not effective in preventing bird collisions. Although some of the measures discussed below can help to reduce the risk to a certain extent under certain conditions, none of them provide sufficient protection for birds.

### Reduced external reflection

Reflections on glass are caused by the difference in brightness in front of and behind the pane. Since the difference between the interior and exterior of buildings is very high, reflections usually remain even if the external reflectance is greatly reduced (section 2.2). So the use of low-reflectance glass (down to 2 % reflectance) on its own and without marking does not constitute effective bird protection. Conversely, however, a higher level of reflectance increases the risk of collisions and reduces the effectiveness of many markings. Functional coatings that reduce the external reflectance are therefore generally preferable to those that increase it.

### Bird of prey silhouettes

It is still common to see silhouettes of birds of prey applied to windows as a supposed bird protection measure. However, these do not have a deterrent effect. Approaching birds do not recognise the silhouettes as potential predators to be avoided. Instead, they perceive them as isolated obstacles and often collide with the unmarked glass right next to them.

*Collision marks are repeatedly found directly adjacent to silhouettes of birds of prey. Cleaning windows less frequently also provides no protection against bird collisions.*

### UV markings

So far there is no scientific evidence that transparent UV markings, whether integrated within the glass, applied as stickers/films or marked with pens, can reliably prevent bird collisions. Whilst certain bird species have a proven ability to see light in the UV range, many native species which have a higher risk of collision, such as birds of prey, woodpeckers, and pigeons, do not have sensors that perceive UV effectively. Moreover, the mechanisms of vision depend on the bird's behaviour at a particular moment in time. In contrast to situations such as foraging or choosing a mate, UV vision plays little or no role for birds in motion, which must quickly detect obstacles in order to avoid them (section 3.2.1).

Moreover, UV levels drop when the sky is overcast or during the morning and evening, when the sun is at a lower angle and flight activity is heightened for many birds.

In experiments, the effect of UV markings tends to be linked to a strong light supply, UV-rich (artificial) light and a bright background. Under poorer light conditions or with a dimly lit background, no effect can be detected in most cases. Neither tests in the Hohenau-Ringelsdorf flight tunnel nor a complementary field study in Bavaria were able to identify a reliable effect: the UV markings performed significantly worse than most of the visible markings (section 3.2.5).

### Lasers for creating fine lines

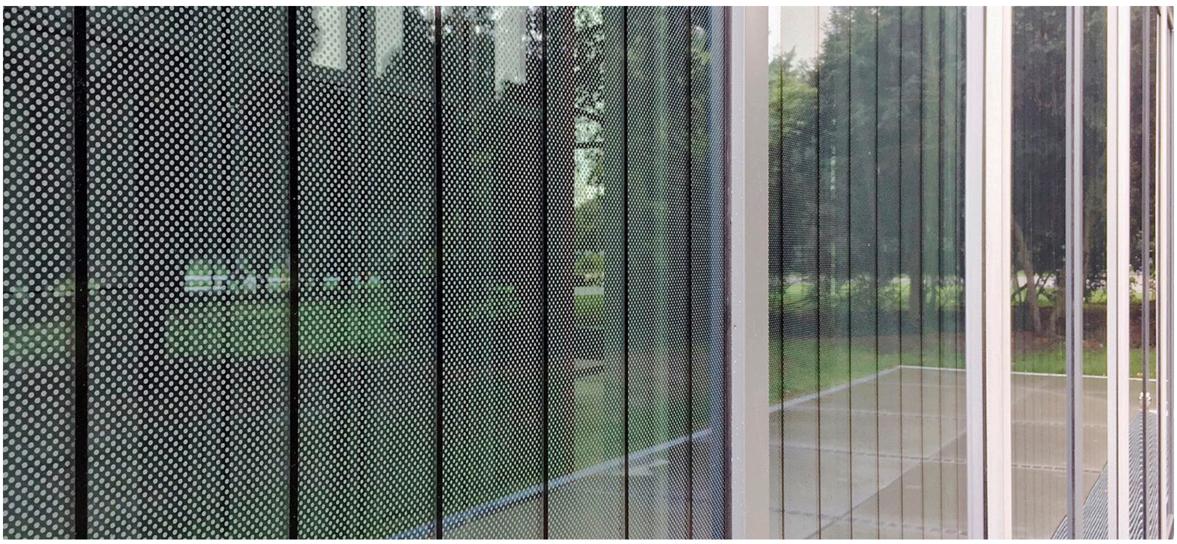
Laser technology can be used to engrave any pattern into coatings or plastics. In principle this includes highly effective markings. However, lasers are mainly used to create precise, very fine structures. These extremely fine lines do not offer the promised protection because birds cannot see them (see illustration p. 49, cf. nets for bird trapping). Laser products should therefore be treated with scepticism. It is advisable to check whether the patterns on offer meet the criteria for effective markings (size, distance, contrast) and whether tests have been carried out. Fine line patterns cannot be expected to provide sufficient protection for birds.

### Coverage rate above 20 or 30 per cent

Since 2005, markings covering between 5 and 10 % of the overall glass surface area have been standard. There are now highly effective markings which cover less than 1 % of the total surface area. In the past, a higher coverage rate (20-25 %) was required for semi-transparent markings (frosted-glass-like stripes); in 2019, however,

*Transparent, UV-reflecting silhouettes are not detected by birds. Sometimes collision marks can actually be found on such stickers.*

one such marking (consisting of interrupted double stripes) was found to be highly effective at a coverage rate of 15 %. So there is no direct correlation between the coverage rate (density) of a marking and its effectiveness. What counts is its detectability (minimum size, sufficient contrast in different light conditions) and the expected behavioural response of the birds (maximum spacing of the marking elements). Less is sometimes more: for example, dense grids of small dots with >10 % coverage rate have proven ineffective.



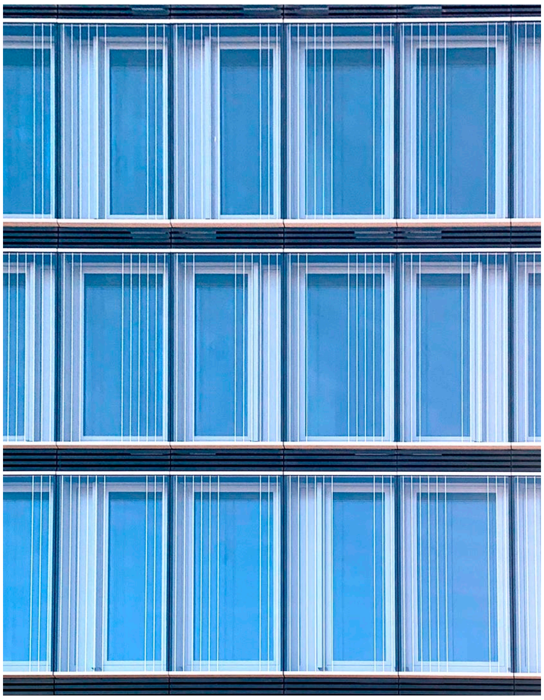
*Bauhaus Museum Dessau: Despite a coverage rate of 30 %, the fine dot grid is unsuitable for bird protection due to its low recognisability for birds. The façade was therefore retrofitted with black stripes.*

**Partial marking of window surfaces**
Bird markings must always be applied to the entire surface of glass panes. This applies to glass surfaces that are very high up as well as to the area of a pane near the ground, as birds are active at all heights. If part of a pane remains unmarked, collisions may continue to occur on the unmarked area.

**Creating shading with recessed glass surfaces**
Dangerous reflections cannot be prevented by shading glass surfaces or by architectural measures such as recessing windows behind canopies or overhangs. Critical situations for birds can also arise here.

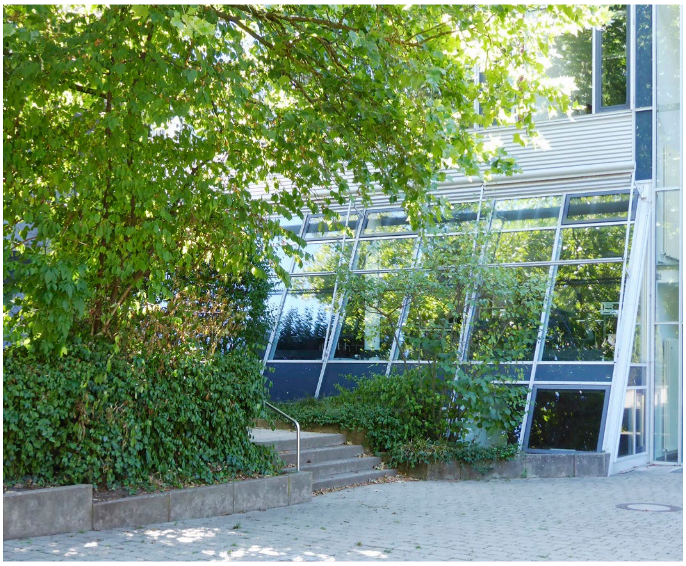
**Sloping glass surfaces**
Inclined glass surfaces can also produce dangerous reflections, and the angle of the pane cannot significantly reduce the impact of a collision. From the point of view of bird protection, only largely horizontal panes such as glass roofs or skylights are considered unproblematic.

**Façade greening**
Green façades in front of glass surfaces can only be considered an effective measure against bird collisions under very specific conditions. The vegetation must be dense enough to prevent birds from flying directly through it, and it must be close enough to the window that birds taking off from the vegetation cannot reach high impact speeds. This is because façade vegetation in front of glass panes is attractive as a food source, refuge, resting or roosting place and thus increases bird density at these potentially dangerous locations.



*Although tested markings were used on this glass façade, the areas left unmarked on each window are too large. This means that collisions can still occur here.*

**Movable sun shades**
External blinds, slats or awnings are not adequate bird protection measures. Although they completely cover the windows behind them when extended, this is always temporary. For the rest of the time, these glass surfaces pose an undiminished risk of collision. Lowering movable sun shades can serve as a simple and



*The reflections on this sloping glass façade of a school building are just as clear as on a vertical pane and thus pose a high risk of collision.*

*When lowered, external blinds can protect against collisions. However, this is user-dependent and therefore not suitable as a permanent solution.*

quick emergency measure when bird collisions are first observed, but it is not suitable as a permanent solution. Light-coloured interior blinds or curtains behind the windows can reduce reflections during the day, but this also does not offer effective bird protection.

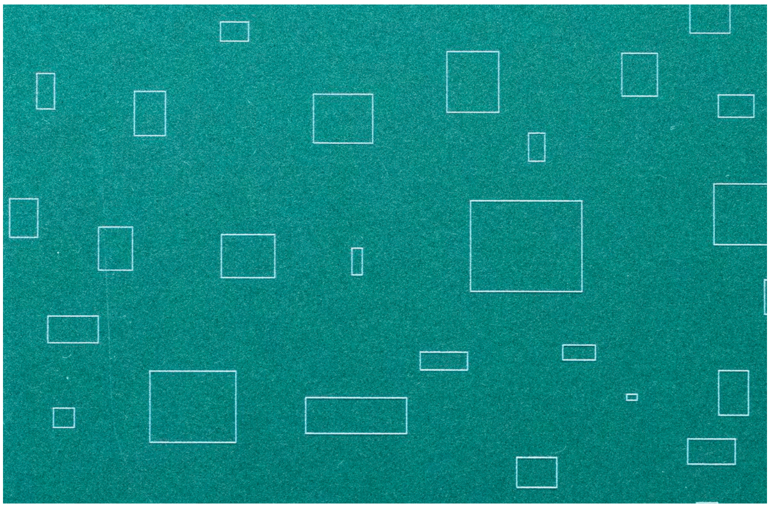
**Insect screens**
Whether insect screens can help birds to recognise a window as an obstruction depends largely on the light conditions. These are therefore not recommended as effective protection against bird collisions.

**Less frequent window cleaning**
As a rule, smudges or dust on glass panes do not sufficiently reduce bird collisions. Impact marks are often particularly visible on unwashed glass surfaces. Freshly cleaned panes, however, have a particularly high collision risk. It is therefore advisable to leave long intervals between window cleaning and to choose periods of low bird activity for cleaning.

**Sun protection films**
Sun protection films can increase the external reflection of a window, creating very clear mirror images. This makes the window even more dangerous for birds. From a bird protection point of view, such sun protection films are therefore only acceptable in combination with effective markings.

**Tinted or coloured glass**
Tinted or coloured glass can also be highly reflective, and the change in colour does not seem to make much difference for birds. Even in situations where birds can see through the pane, tinted glass does not provide reliable protection.

**Acoustic defence measures**
Playing distress cries, warning calls or territorial songs, or emitting unspecific sound pressure waves are not suitable solutions for driving birds away and preventing collisions. In addition, such continuous noises disturb neighbours and passers-by. Ultrasound that is not perceptible to humans also has no effect on birds, as birds hear in roughly the same frequency range as humans.



*Patterns applied with laser technology on or inside the glass panes are usually too fine and cannot be seen quickly enough by birds.*

*Reflective sun protection films create realistic mirror images. To birds, these windows look like arches they can fly through.*

*Even coloured glass produces clear reflections, which can be attractive to birds.*

# 5 Light pollution – environmental effects of artificial lighting

Artificial light can negatively affect many organisms, including humans. In this chapter we take a detailed look at some of the effects on birds, bats, and insects, and suggest lighting technology measures to reduce the impact on wildlife and humans.

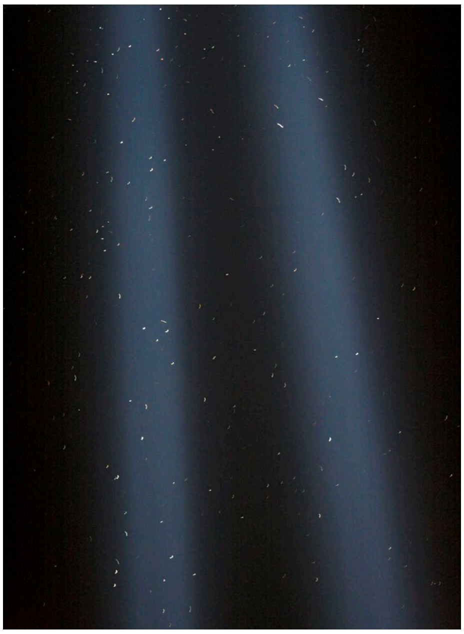
*Lighthouses on Europe's coasts have always shown that artificial light can be a deadly hazard for migratory birds. It is only recently that we have become more aware of the dangers they face inland.*

**Birds**

It has been known for centuries that migratory birds are attracted by strong light sources. On coastlines and at sea, dramatic scenes have been observed of disoriented migratory birds crashing into lighthouses, illuminated wind turbines, oil platforms, and ships.

Further inland, such phenomena have mainly been observed in North America, with large numbers of birds colliding with illuminated skyscrapers, transmission towers and other structures. Migratory birds can be diverted from their flight path by illuminated high-rise buildings or other exposed light sources. The birds fly towards the light source and circle around it in a disoriented manner. As a result, they may collide with the source or other obstacles. In Central Europe, radar technology has confirmed this behaviour in migratory birds passing through the beam of spotlights. Death, stress, and loss of energy are the possible consequences.

Researchers in Central Europe have also gained further insights into the effect of illuminated buildings. One extensively studied building is the 163 m-high Post Tower in Bonn. Here the conspicuous façade lighting and the illuminated company logos on the roof were the main causes of collisions from the late evening hours onwards. Even when the façade lighting was switched off birds flew towards the dim emergency lighting in the corridors of this high-rise



*Every year New York's Tribute in Light commemorates September 11. On seven days across seven years, more than one million migratory birds were caught in the beams of light from the spotlights and became disoriented. Now, the spotlights are temporarily switched off depending on bird activity.*

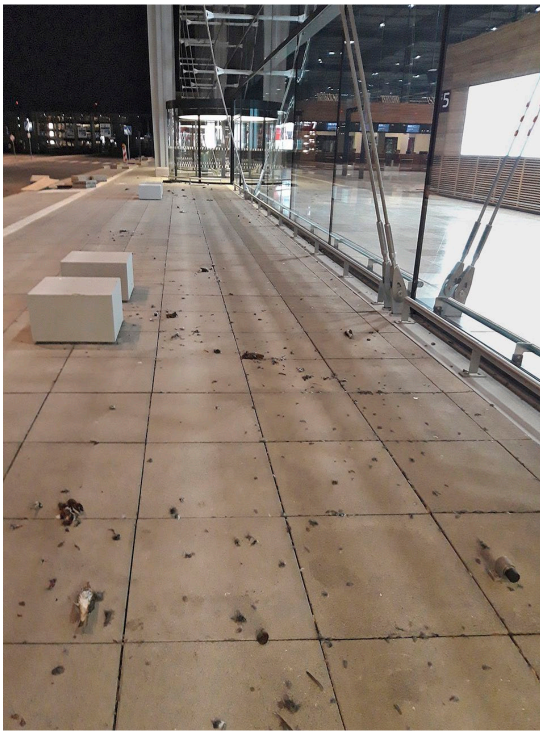
*Effect lighting behind the outer glass façade and illuminated company logos on the roof lure migratory birds to their death at the Post Tower in Bonn. Exposed advertising panels, construction cranes, aviation safety lights, and other light sources high above the ground lie in the flight path of migratory birds and present an often-underestimated threat.*

building throughout the night and collided with the glass panes between them and the light source. The majority of the birds were migratory, most notably Common Firecrests.

In Hamburg, daily carcass searches were carried out in autumn 2020 at three building complexes with façades between 23 and 90 m in height. Numerous collision casualties were found, 77 % of them nocturnal migrants. The most common species were European Robins and Song Thrushes. Although it remained unclear at which heights the birds hit the buildings, it became evident that larger numbers of birds crashed into the more brightly lit façades.

In Berlin, also in 2020, four buildings of up to 42 m in height around the main railway station (Hauptbahnhof) were examined for bird collisions. Direct observations at night found that, as with the Post Tower in Bonn, migratory birds (European Robins and Song Thrushes) collided with the glass façade even at ground level when they flew towards the brightest lighting during the second half of the night. So migratory birds still have an affinity for light even when they have landed after a night's migration.

These findings suggest that brighter light sources at night can attract more migratory birds, even in an



*On a single night of migration, dozens of Song Thrushes collided with the brightly lit terminal of Berlin Brandenburg Airport.*

**Case study: the noctule bat**

The impact of artificial lighting on bats is well illustrated by the case of the noctule bat (*Nyctalus noctula*). In 2019, researchers from the Leibniz Institute for Zoo and Wildlife Research fitted noctules with mini GPS transmitters and recorded their flight paths in the sky over Berlin. The study showed that these bats prefer dark areas in the city and avoid brightly lit, built-up areas. Dark corridors such as urban forests, parks or waterways are of great importance for reaching feeding areas and roosts. Some other bat species are even more sensitive to artificial light.

environment that already has diffuse lighting. This does not necessarily require taller buildings or structures. In fact, there have been numerous cases of nocturnal birds approaching and colliding with buildings a few storeys high within light-polluted urban areas, as well as with small, isolated huts located in dark surroundings. This shows that the decisive factor is the exposure of the light sources to the birds approaching them. Whilst light sources positioned higher up are more exposed and thus more dangerous for migratory birds, light sources lower down can still be dangerous.

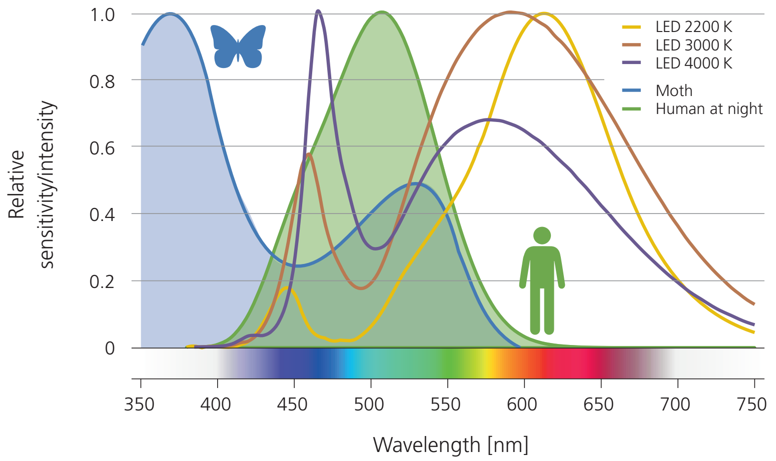
The core periods of bird migration in Central Europe are somewhat staggered regionally from north-east to south-west and generally last from the beginning of February to the end of May and from mid-July to the end of November – although weather conditions can cause some variation. Migratory birds can therefore collide with artificial light sources almost all year round. However, collisions occur most frequently in the autumn months of October and November, when migration volumes reach their peak, frequent headwinds encourage birds to fly at lower altitudes, and critical weather conditions with clouds and fog are more frequent.

**Bats**

Bats avoid light because they can otherwise be easily seen by predators such as birds of prey and owls. Artificially lighting the entrances to bat roosts, such as those found in church roof structures, is particularly problematic. This makes it difficult for the animals to leave the roosts and thus reduces the time spent actively foraging, which can then diminish their reproductive success. Sometimes bats abandon their roosts after a lighting installation, and in extreme cases the animals die of thirst or starvation on site.

*The floodlighting of church roofs makes it difficult for bats to roost. The illumination of vegetation and riparian areas along water bodies is also a problem for fish and insects.*

When foraging or changing locations, different bat species react differently to light. Many bats will avoid illuminated areas even if there are more insects to feed on here. Even a single illuminated street can become an insurmountable barrier for them. Light sources on or adjacent to the natural features that bats use for orientation during migration have a large-scale impact. This in itself is enough reason to question the illumination of bridges or riverbanks; however, such lighting should also be avoided to protect aquatic species.




*The closer the light emissions of LEDs are to the maximum sensitivity of moths' eyes, the more attractive the light source becomes for these insects. At night the human eye is most sensitive at about 500nm. Credits: A. Hänel (modified)*

**Insects**

The light of the moon and stars plays an important role in the orientation of nocturnal flying insects (alongside pheromones), and also determines important steps in their development cycle. Ultraviolet radiation and the short-wave components of the light that is visible to humans (violet, blue to green) are particularly attractive to insects. This is because the eyes of many insects are particularly sensitive within this range. Insects are often attracted to light sources and stray from their habitats. Some burn to death, others die either upon impact or afterwards from exhaustion. If they settle on illuminated façades or on the street, they often fall victim to predators or traffic. Of the more than 4,000 butterfly and moth species in Central Europe, no less than 85 % are nocturnal. Artificial lighting, habitat changes, and the effects of pesticides have drastically reduced the populations of many moth species, as well as other insects, and have brought several species to the brink of extinction.

Yet insects have indispensable functions, for example as links in the food chain and as pollinators of flowering plants – including those we eat. The harmful effects of artificial lighting on numerous animal species, but also on humans, can be minimised with better lighting design and operational measures.

**Lighting design**

Artificial lighting serves to give people a sense of security and facilitate social life in public spaces in the evening and at night. However, light also influences our environment: light emissions have a variety of negative effects on animals, plants, and humans. The main task of a lighting designer is to use a few light points at low heights to achieve uniform illumination, without dazzling people. Glaring islands of light in a dark environment are extremely unpleasant and sometimes dangerous – even for humans – because the eye must constantly adapt to different light conditions.

An ecological reorientation of lighting design is urgently needed. The illumination of the night landscape is increasing globally at a rate of 2-6 % annually. We should therefore critically question the necessity of every new outdoor lighting installation and every adaptation of existing installations. Effect lighting on buildings should be the exception, and there should be no floodlighting of natural objects such as trees and other plants, bodies of water or rock formations. Essentially, a light is most likely to be compatible with nocturnal wildlife when it is switched off.

**Case study: reduction of insect biomass**

In 2017, the publication of a long-term study caused a public stir. Since 1989, entomologists had studied and documented the development of insect populations across 63 areas of the German regions of North Rhine-Westphalia, Rhineland-Palatinate, and Brandenburg. Over this 27-year period, they found that the total mass of flying insects had decreased by more than 75 %. Germany's streetlights alone are believed to kill 150 billion (=150,000,000,000) insects every year.

**Light fixtures**

The best outdoor lights from an environmental point of view are 'full cut-off fixtures'. If correctly installed, these do not emit any light upwards. Another recommendation is to reduce the height of lamp posts: additional light points will be necessary to achieve the same illumination of an area, but this further reduces stray light and glare. Floodlights should be directed downwards from above. Light pollution can also be reduced by confining the beam of light to the target object. To protect insects, shielded fixtures in closed casings with a surface temperature below 60 °C have proven effective. The International Dark Sky Association runs a certification programme for environmentally friendly light fixtures (darksky.org/our-work/lighting/lighting-for-industry/fsa/).

*In the park in the foreground, only the paths can be seen; the lights shine downwards only. In the background, numerous light sources illuminate the night sky and thus contribute to light pollution.*

**Case study: light pollution in Vienna**

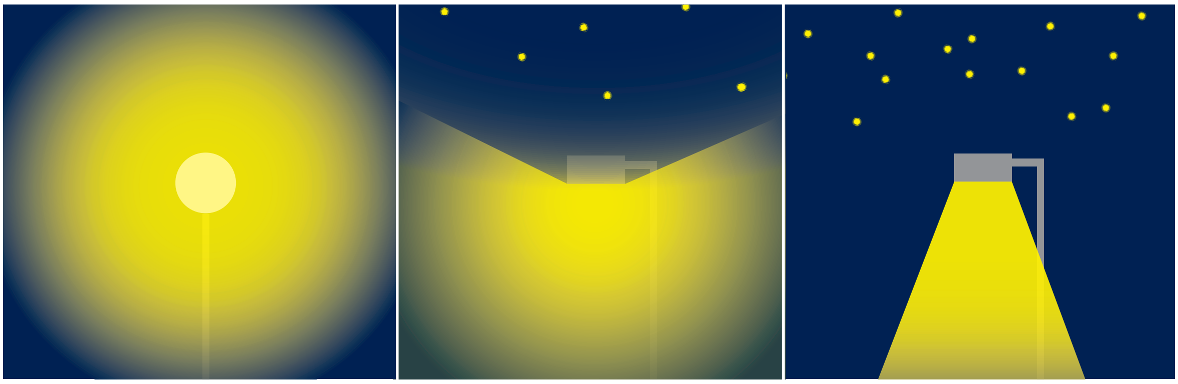
A study in Vienna in 2011 by the Vienna Ombuds Office for Environmental Protection (WUA) showed that two-thirds of light pollution was caused by shop window lighting, floodlights, and other effect lighting. Only one-third was caused by public lighting, despite the latter accounting for two-thirds of all points of light. Modern street lighting is thus responsible for only a relatively small proportion of harmful light emissions.

### Light sources

The actual sources of light used within light fixtures are responsible for the colour quality of the lighting. Light with the same colour temperature can have different spectral compositions. So the colour temperature of a light source expressed in Kelvin does not indicate the short-wave part of the emission spectrum, which is particularly problematic for insects. Today, light-emitting diodes (LEDs) dominate the market for outdoor as well as indoor lighting. However, their lower energy costs should not be equated with environmental friendliness across the board. Just like other light sources, LEDs can contribute to light pollution and harm wildlife. If lighting is required in residential areas with ample vegetation, amber LEDs with a yellowish light should be used (colour temperature approx. 1800-2200 Kelvin). If, in exceptional cases, paths in green spaces need to be illuminated, narrow-band amber LEDs should be chosen. If good colour recognition is required, LEDs with a warm white colour temperature (maximum 2700 Kelvin) can be selected in built-up areas. Cold white light should no longer be used because of its high blue content. Given that LEDs are made up of discrete points of light, special care must be taken to avoid glare. High quality and good shielding are of particular importance with LED lights. LED lights can easily be adjusted to meet requirements using motion sensors or dimmers. These can save energy, lessen the impact on wildlife, and reduce light pollution. At the same time, it is always important to ensure that energy savings are not cancelled out by increased use of light fixtures overall. And it is crucial to avoid creating insect traps: when replacing insect-friendly high-pressure sodium lamps with LED lights, special care should be taken to ensure that they have an emission spectrum with little or no blue component (below 2700, but preferably below 2200 Kelvin).

### Operational measures

When installing artificial light in outdoor spaces, it is crucial to ensure that lights are only used where necessary, only at the required intensity, and only for the required period of time. In less busy areas, the installation of motion detectors, timers, and

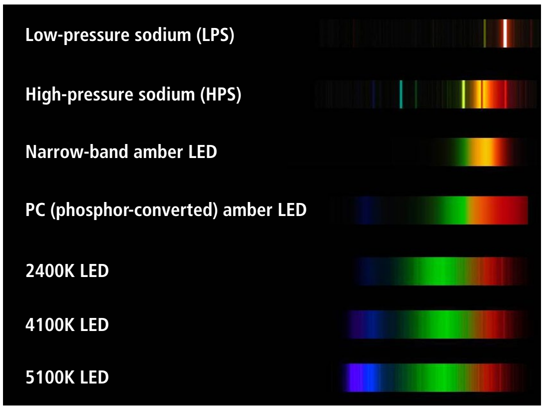



*Globe lights emit light of equal intensity in all directions. This outshines the stars and is particularly attractive for nocturnal insects. Although the standard lamp is shielded at the top, it still emits light from the sides, far into the surrounding area. Lamps designed in line with environmental considerations only emit their light downwards (full cut-off light fixtures). This optimises light output and distribution. From Büro Brauner (modified)*

dimmers can be a useful option. Light fixtures must be checked and adjusted periodically.

Indoor lighting that radiates outwards can also contribute to light pollution if appropriate countermeasures are not taken. Blinds that are closed automatically at dusk and raised manually in the morning can help, as can light-proof curtains and a lighting system that is tailored to business hours.

Resting migratory birds can be disturbed in their day-night rhythms, while exposed light sources distract migrating birds from their route and sometimes attract them, leading to collisions with windows or other obstacles. We recommend that preventive measures be put in place at least during periods of bird migration. This applies especially to topographically exposed buildings on coasts, inland water bodies, or on mountain passes, but also to high-rise buildings that are visible from afar. Lighting not required for safety reasons can be switched off completely or at least between 10 p.m. and sunrise, and blinds should be closed at nightfall. For aviation safety lights on tall buildings, preference should be given to lighting with longer dark phases and the shortest possible bright phases rather than rotating or, worse, steady-burning lights. Strobe or flashing lights are more favourable than blinking lights when it comes to bird conservation.




*Light spectra of different light sources: low-pressure sodium (LPS), high-pressure sodium (HPS), and LEDs with different colour temperatures. These illustrations of the spectra are from Flagstaff Darksky Coalition (http://www.flagstaffdarkskies.org/for-wonks/lamp-spectrum-light-pollution).*

**Case study: Jungfraujoch, Switzerland**

An extreme case of effect lighting is the Jungfraujoch, an alpine pass at 3471 m elevation in the Bernese Highlands in Switzerland. A simple measure taken here – switching off the illumination of the observatory, the 'Sphinx', on foggy nights – has proven very successful, saving the lives of countless migratory birds.

# 6 At a glance

## 6.1 Key points

### Avoid problematic glass surfaces

- Avoid free-standing transparent panes
- Avoid highly reflective glass or metal elements
- Avoid corner glazing or large opposing panes with transparent areas (e.g. in stairwells, connecting corridors, car showrooms)
- Use translucent glass, profiled glass, glass blocks or opaque materials (e.g. metal railings, balustrades)
- Use façade cladding made of permanently installed slats, wooden battens or metal mesh

### Effectively mark unavoidable glass surfaces

- Use markings which have tested as 'highly effective'
- For free-standing glass walls, markings can be fitted on either side
- If reflections occur, markings must always be on the outside of the pane (for exceptions see the test reports on the products which tested as 'highly effective')
- Markings must contrast strongly with their background (black, white, orange, red and metallic silver have proven effective)
- In cases of low contrast (e.g. semi-transparent films), the required coverage is 20-25 %
- Criteria for highly effective markings, with maximum contrast:
  - Horizontal lines: min. 3 mm wide, 50 mm distance between edges
  - Vertical lines: min. 5 mm wide, 100 mm distance between edges
  - Black dots: min. 10 mm diameter, in 90 mm grid
  - Metallic reflective dots: min. 9 mm diameter, in 90 mm grid
- The marking must cover the entire glass surface
- Only tested markings guarantee highly effective bird protection!

**Reduce negative impact of artificial lighting**

- Only where necessary
- Only at the required intensity
- Only during the periods when it is needed
- Do not illuminate natural objects
- Avoid the illumination of buildings as far as possible; restrict lighting to particular seasons and times and focus the light beam on the object to be illuminated
- Illuminate from above whenever possible
- Use shielded lamps with closed casing
- Surface temperature below 60 °C
- To protect insects, minimise short-wave components in the spectral range of the lighting and avoid these altogether in near-natural areas
- Buildings with bat roost entrances must not be illuminated
- Avoid light emissions from inside buildings

## 6.2 Dangerous glass surfaces

Which parts of buildings carry the greatest risk of collision for birds? Transparent glass surfaces which suggest a clear flight path and window panes which reflect habitats cause birds to collide with glass. The following illustration shows problem areas in different parts of buildings.

**1 Fence**

Free-standing transparent glass elements are particularly dangerous for birds.

**2 Corner glazing**

Glazed corners give the impression of a free passage.

**3 Glass balcony balustrade**

Transparent balustrades are often not visible to birds.

**4 Large windows**

Large glass panes significantly increase reflections and thus the risk of collision.

**5 Bicycle shelter**

Shelters made of transparent glass are a dangerous obstacle.

**6 Conservatory**

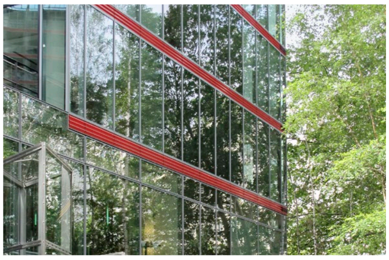
Transparent conservatories can be a deadly trap for birds in our gardens.

**7 Noise barrier**

Insufficiently marked glass noise barriers are extremely dangerous for birds.

**8 Public transport shelter**

Without highly effective markings, public transport shelters are very dangerous for birds.



**9 Glass façade**

Larger glass façades create more extensive reflections and greater hazards for birds.

**10 Safety barrier**

These are designed to keep people safe, but pose a deadly threat to birds.

**11 Passageway/enclosed bridge**

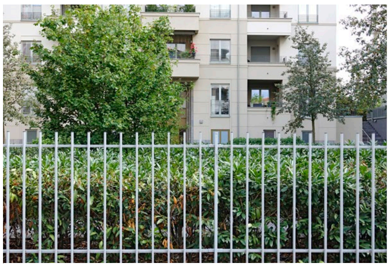
Glass passageways are a dangerous obstacle to flying birds, who cannot see the panes.

**12 Ribbon windows**

Compared to building façades with smaller, punched windows, the reflections of such extended ribbon windows cover a larger area and are therefore more problematic

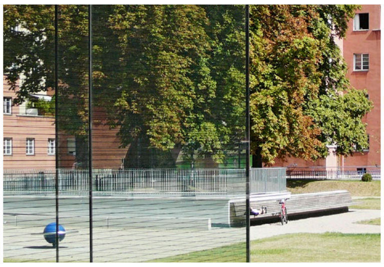
## 6.3 Bird-friendly solutions

Many classic bird traps can be avoided by using alternative materials. If transparent or reflective glass is used nonetheless, the potentially dangerous panes must be provided with bird protection markings in order to reduce collisions as much as possible. There are many ways to do this without significant impact on the user experience.



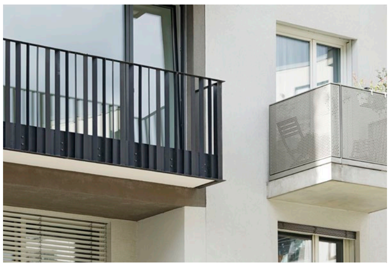
**1 Fence**

There are numerous bird-friendly alternatives for property boundaries.



**2 Corner glazing**

Markings can be used to make transparent building corners visible to birds.



**3 Balcony balustrades**

As with fences, there are many alternatives to glass for balcony balustrades.

**4 Large windows**

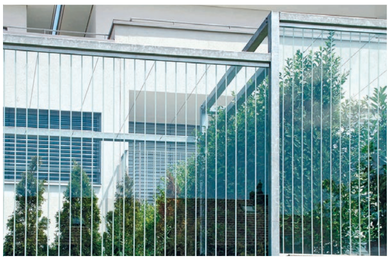
Markings can be used to make large, reflective surfaces bird-friendly.

**5 Bicycle shelter**

Translucent or marked glass can be used to prevent bird collisions.

**6 Conservatory**

Highly effective markings are the only bird-friendly solution here.



**7 Noise barrier**

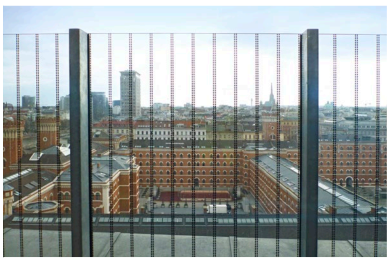
Markings on transparent noise barriers should be standard by now.

**8 Public transport shelter**

Effective markings are easy to apply without reducing the users' sense of safety.

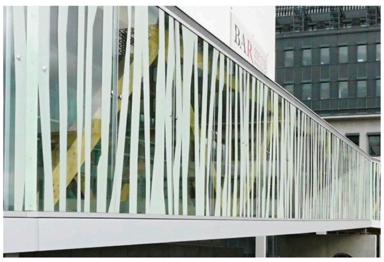
**9 Glass façade**

Effective bird protection need not come at the expense of a high-quality interior space.



**10 Safety barrier**

Marked barriers protect birds from collisions.



**11 Passageway/enclosed bridge**

There are various options for bird-friendly passageways.

**12 Ribbon windows**

Long bands of reflective windows must be marked or replaced by other types of façade.

# Further information

## Glass

www.vogelglas.vogelwarte.ch
www.wua-wien.at
www.bund-nrw.de/themen/vogelschlag-an-glas
www.lbv.de/ratgeber/lebensraum-haus/gefahren-durch-glas
www.birdlife.ch/de/glas
www.birdsandbuildings.de
www.lfu.bayern.de/natur/vogelschutz/vogelschlag/index.htm
www.nabu.de/tiere-und-pflanzen/voegel/helfen/01079.html
www.abcbirds.org/glass-collisions
www.birdsafe.ca
www.nycaudubon.org/our-work/conservation/project-safe-flight/bird-friendly-building-design

## Light

www.bafu.admin.ch/bafu/de/home/themen/elektrosmog/fachinformationen/lichtemissionen-lichtverschmutzung-.html
www.helldunkel.ch
www.hellenot.org
www.lichtverschmutzung.de
www.darksky.org
www.flap.org
www.wua-wien.at

## Further links

www.vogelwarte.ch/de/home
www.wua-wien.at
www.bund.net
www.lbv.de
www.birdlife.ch
www.lipu.it
www.lpo.fr
www.bfn.de
www.vogelschutzwarten.de
www.darksky.ch/dss/de
www.ornitologia.org/ca
www.seo.org

## Contact addresses for expert advice

The following organisations are happy to provide specialist advice for their areas of responsibility within the scope of their possibilities. For this purpose, they require building plans, visualisations and/or pictures of existing buildings (incl. surroundings). In any case, the glass must be clearly marked on the plans.

### Germany

BIRDS AND BUILDINGS
Forsterstr. 40
10999 Berlin
Tel. +49 030 817 978 07
hello@birdsandbuildings.de

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Landesgeschäftsstelle
Eisvogelweg 1
91161 Hilpoltstein
Tel. +49 921 759 42 16
vogelschlag@lbv.de

NABU (Naturschutzbund Deutschland) e.V.
Bundesgeschäftsstelle
Charitéstraße 3
10117 Berlin
Tel. +49 030 284 984 60 00
Vogelschutz@NABU.de

### Austria

Wiener Umweltanwaltschaft
Muthgasse 62
1190 Wien
Tel. +43 1 379 79
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### Switzerland

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Seerose 1
6204 Sempach
Tel. +41 41 462 97 00
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8036 Zürich
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glas@birdlife.ch