Chapter 14
Bats and Buildings: The Conservation of Synanthropic Bats

Christian C. Voigt, Kendra L. Phelps, Luis F. Aguirre, M. Corrie Schoeman, Juliet Vanitharani and Akbar Zubaid

Abstract Humans have shared buildings with bats for thousands of years, probably as early as first humans built primitive huts. Indeed, many bat species can be defined as synanthropic, i.e., they have a strong ecological association with humans. Bats have been observed using buildings as roosting and foraging sites, temporary shelters, for reproduction and hibernation. A synanthropic lifestyle may result in direct fitness benefits owing to energetic advantages in warmer roosts, which may ultimately lead to more rapid gestation and faster development of juveniles, or by being less exposed to natural predators in urban environments. All

Luis F. Aguirre, M. Corrie Schoeman, Juliet Vanitharani and Akbar Zubaid: Contributed equally, listed alphabetically.

C.C. Voigt (✉)
Department of Evolutionary Ecology, Leibniz Institute for Zoo and Wildlife Research, Berlin, Germany
e-mail: ccvoigt@googlemail.com

K.L. Phelps
Department of Biological Sciences, Texas Tech University, Lubbock, USA

L.F. Aguirre
Centro de Biodiversida y Genetica, UniversidadMajor de San Simon, Cochabamba, Bolivia

M. Corrie Schoeman
School of Life Sciences, University of KwaZulu-Natal, Durban, South Africa

J. Vanitharani
Department Advanced Zoology and Biotechnology and Research Centre, Sarah Tucker College, Palayamkottai, Tirunelveli, Tamil Nadu, India

A. Zubaid
School of Environmental and Natural Resource Sciences, Faculty of Science and Technology, Universiti Kebangsaan Malaysia, 43600 Bangi, Malaysia

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these benefits may allow bats to use buildings as stepping stones to exploit habitats otherwise devoid of roosting structures and may even lead to the expansion of geographic ranges. Yet, the coexistence with humans also comes with some risks. Bats may be exposed to chemical pollutants, particularly preservation chemicals used on lumber or during pest control measures. Bats may also be at risk of direct persecution or they may die accidently if trapped within buildings. In general, eviction of bats from buildings should follow the general rule of avoidance–mitigation–compensation. When considering conservation measures for synanthropic bats, it is most important to assess the role of the building for different life stages of bats. Construction work at buildings should be conducted in a manner that minimizes disturbance of bats. Artificial roosts can replace lost roosts, yet bats will often not accept alternative roosts. Demographic changes in human populations may lead to the abandonment of buildings, for example, in rural areas and to increased conflicts in urban areas when old buildings are replaced by new buildings or when previously unoccupied space in buildings is renovated. We advocate maintenance and enhancement of roosts for synanthropic bats, in addition to outreach and education campaigns, to improve the tolerance of humans for synanthropic bats.

14.1 Introduction

14.1.1 What Is the Purpose of This Review?

Bats are nocturnal mammals that spend the daytime in dark places (Kunz 1982; Kunz and Lumsden 2003). Usually, they depend on natural roosting structures such as caves, crevices, foliage, branches, tree trunks, and hollows among many others. Bats most likely used buildings as roosts when humans started to build primitive huts thousands of years ago. Indeed, some bat species, such as the hairy split-faced bat, *Nycteris macrotis*, inhabit thatched huts in Africa that are likely similar to the earliest buildings of humans (Poché 1975).

In this chapter, we focus on bats that use man-made buildings that are coinhabited by humans. We refer to these bats as synanthropic species, or species that are "ecologically associated with humans (Merriam-Webster's dictionary). We do not use synanthropic species in the context of bats living in anthropogenically shaped landscapes; rather, this topic is covered in Chap. 2 (Reichel-Jung and Threlfall 2015). Nonetheless, we address certain aspects of bats living in other man-made structures unoccupied or abandoned by humans.

Synanthropic bat species have benefited from the expansion of human populations, and some species have likely expanded their geographic distribution as humans moved into new habitats worldwide. Yet this close association has disadvantages when synanthropic bats are faced with threats from humans. Currently, about a quarter of all bat species are considered threatened or near threatened, and one of the most prominent threats is loss of roost sites and disturbance at roosts (Mickleburgh et al. 2002). Therefore, this chapter is timely, and we hope that it will contribute to the conservation of synanthropic bats.

14.1.2 Relevant Natural History Features of Synanthropic Bats

Along the fast–slow continuum of life, bats are considered to be in the slow lane, even though most other mammals of similar size are in the fast lane (Barclay and Harder 2003; Bielby et al. 2007). Bats have low reproductive rates that are associated with exceptionally long life spans, a feature most obvious in insectivorous bats from temperate zones (Wilkinson and South 2002; Munshi-South and Wilkinson 2010). Long life spans may predispose bats to inhabit relatively permanent structures, such as in buildings, since some bat species are loyal to their roost over many years and form long-term social relationships with other colony members (Kerth et al. 2011).

Similar to other small mammals, bats exhibit relatively high mass-specific metabolic rates (McNab 2002). Many bats are also heterothermic, reducing their body temperature and consequently metabolic rate, during periods of adverse conditions, such as low resource abundance (insects, fruits, or nectar), low ambient temperature, or high rainfall (Geiser 2004). Most notably, temperate zone bats employ extended torpor when they hibernate in winter. Apart from hibernation, almost all bats use torpor on a daily basis as an energy-saving strategy (Speakman and Thomas 2003; Willis et al. 2006). During daytime torpor, bats may use passive rewarming when ambient temperatures peak during the warmest part of the day (Turbill et al. 2003). The use of radiant heat created by the exposure of building exteriors to sunshine likely saves synanthropic bats significant amounts of energy since they do not depend on endogenous heat production in brown adipose tissue (Geiser and Drury 2003). This could be a selective advantage for bats using sun-exposed buildings instead of dark caves as daytime roosts or hibernacula (Lausen and Barclay 2006; Halsall et al. 2012).

14.1.3 Which Bat Species Use Buildings?

The order Chiroptera comprises 19 living families, with at least one species in each family known to roost in buildings (Figs. 14.1 and 14.2), with the notable exceptions of Furipteridae, Mystacinidae, Myzopodidae, Natalidae, and Thyropteridae. Quite often, only local residents are aware of the occurrence of synanthropic bat species. The chapter on bats and urbanization (Reichel-Jung and Threlfall 2015) provides a meta-analytic perspective on bats living in urban landscapes. Many of the species included in their analysis also roost in buildings; thus, the general patterns derived from their study may also hold true for aspects of roost choice in synanthropic bats.

Fig. 14.1 Example of synanthropic bats that use both natural roosts and buildings. The greater sac-winged bat, *Saccopteryx bilineata*, shown here in Costa Rica, forms colonies in the cavities formed by large buttress roots of canopy trees. In the absence of such trees, this species will roost on the exterior walls of buildings (or inside if the building is abandoned as shown in the *right picture*; © *left picture* Knörnschild M, right picture Voigt CC)

Fig. 14.2 Colony of *Megaderma lyra* under a tin roof of a building in India

14.1.4 Human–Bat Conflict in Buildings and the Legal Protection of Synanthropic Bats

Buildings constructed specifically as human dwellings are usually well maintained and protected against opportunistic invasions by unwanted animals. Unfortunately, synanthropic bats are unwanted by most humans, which generate conflicts (Gareca et al. 2007). Accordingly, synanthropic bats are persecuted virtually worldwide, even if the legal framework may define this action as criminal. Documented cases of humans removing bats from buildings are apparent across the entire geographic range of synanthropic bats (e.g., Merzlikin 2002), but most cases remain unnoticed by law enforcement agencies even where bats are legally protected. Indeed, bats are legally protected in only a few countries. For example, bats are protected in countries of the European Union according to the Habitats Directive (Council Directive 92/43/EEC). Also, migratory bats are specifically protected in countries that have signed the United Nations convention on the "Conservation of Migratory Species of Wild Animals" (Lyster 1989). In some countries, conservationists have established action plans for threatened bat species, including suggestions for protecting synanthropic bats (Aguirre et al. 2010). However, these recommendations have not yet been converted into some form of legal framework. In African and Asian countries, bats are not protected under specific legislation. In summary, the level of protection of synanthropic bats by national or international legislation is highly variable and clearly deficient.

14.2 How Do Bats Find and Use Buildings?

Since most bat species are not capable of constructing their own roosts (Kunz 1982; Kunz and Lumsden 2003), they depend largely on preexisting roosting structures, either of natural or of artificial origin. Therefore, roost sites are likely a limited resource for bats (Kunz 1982; Kunz and Lumsden 2003), such that buildings may constitute an important substitute for natural roosts (Lisón et al. 2013). Buildings may resemble rocks or cavelike structures, which may attract bats into crevices or attics. Once one or a few bats establish a roost in a building, other bats may recognize the newly established roosts by olfactory or acoustic cues. The importance of nonsocial information such as visual and temperature-related cues and social sensory cues, e.g., conspecific echolocation calls, has recently been confirmed as important information for the common noctule bat, *Nyctalus noctula*, to initiate roost exploration (Ruczyński et al. 2007). Presumably, noctule bats use the same set of cues for exploring buildings as temporary shelters or hibernacula (Bihari 2004; Kozhurina and Gorbunova 2004; Szodoray-Parádi et al. 2004; Cel'uch and Kaňuch 2005; Cel'uch et al. 2006; Bačkor et al. 2007).

14.2.1 Buildings as Foraging Sites

Buildings are rarely used by bats as foraging sites, although abandoned buildings may develop into small urban ecosystems. For example, Aspetsberger et al. (2003) found that cockroaches (Blattodea: Blaberidae), sharing the space under the metal roof of a building with little free-tailed bats, *Chaerephon pumilus*, comprised more than 60 % of the diet of the bats. Yet, most observations of foraging at buildings are bats hunting insects around illuminated buildings. Artificial lighting is known to attract insects, and consequently, bats may chase insects close to illuminated buildings (Rydell 1991, 1992; Rydell and Racey 1995; Pavey 1999; Rowse et al. 2015).

14.2.2 Buildings as Shelters During Foraging Bouts

Buildings provide structures that can be used by bats as a temporary shelter. For example, buildings are often used by bats as a shelter to digest food items gathered during their most recent foraging bout (Ormsbee et al. 2007). This behavior has been observed in many species, including tropical carnivorous species such as the greater false vampire bat, *Megaderma lyra*, in India (Subbaraj and Balasingh 1996), and the greater slit-faced bat, *Nycteris grandis*, in southern Africa (Fenton et al. 1990) as well as temperate insectivorous bats such as Leisler's bat, *Nyctalus leisleri*, in Europe (Shiel et al. 1999), and the pallid bat, *Antrozous pallidus*, in the USA (Lewis 1994). In general, the temporary use of buildings by foraging bats may be the first step toward a more permanent occupation of buildings.

14.2.3 Buildings as Maternity Roosts

Females of many synanthropic bats use buildings as maternity roosts. Sometimes adult males share the same roost, but often the sexes are segregated. According to our literature survey, at least 35 bat species form maternity colonies in buildings. Energetic advantages and reduced predation risk may be benefits for female bats that give birth and raise their young in buildings. Harbusch and Racey (2006) reported that the serotine bat, *Eptesicus serotinus*, selected old buildings with slate roofing for maternity roosts, largely because such buildings tend to have small holes and fissures allowing easy access. Also, such buildings offered suitable temperatures of about 22 °C during gestation and lactation periods, a critical parameter for the survival of offspring (Harbusch and Racey 2006). Further, many species that form maternity colonies in buildings show high levels of site fidelity and natal philopatry, with female young returning to the same roosts to reproduce when they mature (Harbusch and Racey 2006). This could initiate a tradition of using buildings instead of natural roosts in local bat populations.

14.2.4 Buildings as Swarming Sites

Several European bats, such as common pipistrelle bats, *Pipistrellus pipistrellus*, and parti-colored bats, *Vespertilio murinus*, swarm at large buildings during autumn (Kanuch et al. 2010; Šuba et al. 2010). Usually, swarming occurs after juveniles have fledged and as they start to disperse from their natal roost. In Marburg, Germany, common pipistrelles swarm between mid-August and late September not only at tall buildings, such as historic towers, castles, and churches, but also at large multistory buildings. Interestingly, bat researchers recorded almost exclusively juvenile bats during swarming events (Kanuch et al. 2010; Šuba et al. 2010), and therefore, it was argued that swarming was related to roost exploration (Smit-Viergutz and Simon 2000). Yet, a social function of swarming behavior has also been suggested, for example, for *Vespertio murinus* (Kanuch et al. 2010; Šuba et al. 2010). To the best of our knowledge, swarming of bats at buildings has not been observed in countries outside of Europe.

14.2.5 Buildings as Hibernacula

Many bat species are known to hibernate in buildings, presumably because building interiors rarely reach freezing temperatures, turning them into ideal hibernation sites for bats. For many of these species, natural hibernacula include not only caves, rock crevices, and rock screes, but also tree hollows. Michaelsen et al. (2013) reported that in Norway, hibernating bats prefer anthropogenic structures rather than natural subground hibernacula, but the reason for this preference was unknown. Bats, such as big brown bats, *Eptesicus fuscus*, hibernating in walls of heated buildings expose themselves to ambient temperatures of 2–5 °C which are created by the balance between warm interior temperatures from heated rooms and cold ambient temperatures from the outside (Whitaker and Gummer 1992). In addition, bats hibernating in buildings may also benefit from occasional passive rewarming, when being exposed to mild exterior temperatures. *Nyctalus noctula* usually forms maternity colonies in tree roosts, yet in Central and northern Europe, they frequently use prefabricated buildings, i.e., multistory buildings consisting of prefabricated concrete walls that are assembled at the construction site. Throughout continental Europe, large numbers of noctule bats hibernate in such buildings in crevices at about 5–10 m aboveground, sometimes forming winter aggregations of a few thousand individuals (Zahn et al. 2000; Kozhurina and Gorbunova 2004; Cel'uch and Kaňuch 2005; Cel'uch et al. 2006). Bats in subtropical and tropical zones may also use buildings during adverse conditions and employ torpor, yet their biology is largely unknown and therefore in need of further studies.

14.3 Benefits of a Synanthropic Lifestyle in Bats

14.3.1 Increased Fitness of Bats Using Buildings

Bats would not use buildings as roosts without a proximate (ecological or physiological) or ultimate (evolutionary) benefit. In the following, we will discuss three potential benefits for bats using buildings, which seem to be linked to increased fitness over the short or long term.

Reduced predation risk In general, bats face only a few predators compared to non-volant mammals of similar size (Sibly and Brown 2007). Yet some birds, mammals, and even invertebrates hunt bats on a regular basis (Gillette and Kimbrough 1970; Speakman 1991; Altringham 1996; Nyffeker and Knörnschild 2013). Roosts in buildings could reduce the exposure of bats to predators if predators avoid anthropogenic environments. For example, snakes and giant centipedes hunt neotropical bats at the entrance of caves, and many of these species are less abundant or even absent in an urban environment (Molinari et al. 2005; Esbérard and Vrcibradic 2007). In North America, big brown bats, *E. fuscus*, seem to be less exposed to predators when roosting in buildings than in natural roosts (Lausen and Barclay 2006). However, clustered emergence of bats from roosts in buildings may point to antipredatory behavior in synanthropic bats in urban environments (Speakman et al. 1995; Duvergé et al. 2008; but see Irwin and Speakman 2003).

Energetic benefits Bats may survive periods of adverse weather conditions, such as heavy rain or low ambient temperatures, by roosting in a warm and dry building. The energetic benefits for bats roosting in buildings may manifest particularly during critical life history stages, such as reproduction and hibernation.

Buildings may provide conditions that are beneficial for reproducing female bats. For example, elevated ambient temperatures in attics seem to be ideal for pregnant and lactating bats. Angolan free-tailed bats, *Mops condylurus*, inhabit maternity roosts under corrugated steel roofs of houses that often exceed 40 °C during the day (Maloney et al. 1999), enabling them to maintain ideal growth conditions throughout the reproductive period without expending a lot of energy (Vivier and van der Merwe 2007). Their use of hot roosts may even be linked to increased reproductive rates (Bronner et al. 1999). Higher roost temperatures in attics seem to be also favorable for the development of juveniles of European greater mouse-eared bats, *Myotis myotis*. This species forms large clusters of individuals in natural cave roosts, presumably to benefit from huddling and sharing of body heat (Dietz et al. 2009). In buildings, however, greater mouse-eared bats usually form smaller colonies, and these smaller clusters may be energetically feasible only because *Myotis myotis* may benefit from exogenous instead of endogenous heat when roosting in warm attics (Zahn 1999). The use of different locations depending on reproductive state has been confirmed for other species as well, including Rafinesque's big-eared bats, *Corynorhinus rafinesquii* (Roby et al. 2011). Similar to attic-roosting *Myotis myotis*, thermal benefits have also been suggested for *Eptesicus fuscus*. Pregnant big brown bats rarely entered torpor when roosting at favorable ambient conditions in buildings (Lausen and Barclay 2006). The avoidance of torpor may be advantageous for fetal development. For example, big brown bats gave birth earlier when roosting in buildings than when roosting in natural roosts. Furthermore, juveniles from buildings fledged one to two weeks earlier than conspecifics born in natural roosts (Lausen and Barclay 2006). Similarly, building-dwelling bats gave birth earlier than their conspecifics roosting in foliage or trees (Kurta 2010). These temporal differences could translate to important advantages for building-roosting juveniles; for example, they have more time to explore new roosts and foraging sites and to prepare for the onset of hibernation.

Hibernating bats may also benefit from thermal advantages in buildings. For example, thermoregulation of *E. fuscus* hibernating in buildings was more similar to that of tree-dwelling species than to that of cave-hibernating conspecifics (Halsall et al. 2012). The authors argued that bats hibernating in buildings may benefit to a larger extent from passive rewarming (Halsall et al. 2012), which may lead to massive savings of crucial fat depots (Turbill et al. 2003; Geiser and Drury 2003). This notion is also supported by the observation that some bats, such as *Nyctalus noctula*, choose crevices behind sun-exposed walls when hibernating in buildings (Bihari and Bakos 2001).

In addition to thermal benefits, synanthropic bats may also benefit by reducing their travel distance and thus time to foraging sites, resulting in substantial energetic savings from reduced commuting distances (Knight and Jones 2009).

Presence of social or mating partners If buildings are selected as roost sites by a single bat, conspecifics may follow to benefit from social advantages (Kerth 2008). These secondary social benefits for synanthropic bats are identical to those of conspecific roosting in natural roosts. Briefly, bats that form large colonies in buildings may be less exposed to predators because of the dilution effect. They may as well benefit from information transfer and by cooperation among members of the same social unit. Clustered emergence of bats from a roost may constitute an antipredator behavior (Speakman et al. 1995), yet clustered emergence may be disrupted in large colonies due to bottleneck effects (Speakman et al. 1999). Gillam et al. (2011) found non-random patterns when pit-tagged *Eptesicus fuscus* emerged from buildings, indicating that these bats may form social bonds that likely influence their foraging. Information transfer might also be involved during swarming at buildings as observed in some temperate zone bats (Kanuch et al. 2010; Šuba et al. 2010). Finally, bats may explore buildings in search of mating partners. For example, buildings are known to be used as mating roosts in a number of species, such as greater sac-winged bats, *Saccopteryx bilineata* (Bradbury and Emmons 1974; Bradbury and Vehrencamp 1976), greater mouse-eared bats, *Myotis myotis* (Dietz et al. 2009), spear-nosed bat, *Phyllostomus hastatus* (Santos et al. 2003), and free-tailed bats, such as *Tadarida brasiliensis* and *Mops condylurus* (Vivier and van der Merwe 2001).

14.3.2 Enhanced Access to Habitats by Using Buildings as Ecological Stepping Stones

Extending the aforementioned argument that bats may benefit from using buildings as shelters by shortening travel distances to foraging habitats, one could argue that bats may even be able to explore and exploit new habitats by using buildings as ecological stepping stones. For example, some uniform and homogenous agricultural habitats, such as the former prairies of the Midwestern USA, are nearly void of roosting structures. Therefore, it is almost impossible for aerial-hawking insectivorous bats to use these habitats, unless artificial roosting structures are available. Here, buildings may present pivotal resources for bats to survive in an otherwise hostile environment. Farm buildings, villages, and cities may create structurally complex islands used by bat colonies (Coleman and Barclay 2012a), and this could possibly lead to an increase in local species richness. Some synanthropic bats, such as *Mops condylurus*, are capable of using exceedingly hot roosts (40 °C) which allow them to colonize habitats that other bats with a lower tolerance toward high roost temperatures are not able to exploit (Maloney et al. 1999), suggesting that heat tolerance might be favorable for bats with a synanthropic lifestyle.

In forested areas, buildings may provide roosting structures for cave-roosting bats, i.e., for bats that do not use tree hollows or crevices. By using buildings as roosts, these bats may gain access to other habitats. For example, in a forest habitat in Central Europe, bats that typically do not occupy tree cavities, such as *Eptesicus serotinus* and *Vespertilio murinus*, will instead inhabit buildings. By doing this, they gain access to insect-rich forest habitats (Mazurska and Ruczyński 2008).

Buildings can also provide roosting sites for cave-roosting bats in urban areas. For example, *Otomops martiensseni* exploits buildings only in the city of Durban, South Africa, while elsewhere in its range it uses caves as roosts. Despite the reduced availability of food and intensive large-scale agricultural land use in the surrounding landscape, the species is quite common in Durban (Fenton et al. 2002). Similarly, Moutou's free-tailed bat, *Mormopterus francoismoutoui*, uses a variety of human structures (e.g., roof slats, window shutters) across the island of La Réunion, Mauritius, yet it was thought to be restricted to roosts in lava tubes and crevices along cliff faces before the colonization of the island by European settlers (~AD 1500; Goodman et al. 2008a). Seemingly, this species has profited from the large-scale changes that occurred on this island over the past centuries. In summary, buildings may present an important resource for synanthropic bats that could increase foraging ranges of individual bats as well as the diversity of local bat assemblages.

14.3.3 Expansion of Geographic Ranges

The use of buildings as roosts may also lead to the expansion of a species' geographic range (Kunz and Reynolds 2003). Some temperate bat species such as greater mouse-eared bats, *Myotis myotis*, and lesser and greater horseshoe bats, *Rhinolophus hipposideros* and *Rhinolophus ferrumequinum*, respectively, predominantly form maternity roosts in caves in southern Europe but occupy mostly attics of large buildings (e.g., churches and castles) in more northern regions of their geographic ranges where cave temperatures are too cold to host cave-roosting maternity colonies (Dietz et al. 2009). The notch-eared bat, *Myotis emarginatus*, also uses buildings as maternity roosts in the northernmost part of their range in Europe (Dekker et al. 2013). Frafjord (2007) observed a small nursery colony of the northern bat, *Eptesicus nilssonii*, in the attic of a cabin at the northern extent of the species range. The roost was only occupied when human inhabitants heated the house for their own use, giving support to the idea that bats benefited from the warmer roost temperatures. The use of buildings as a driving force to reach more northern limits of their geographic ranges (in the Northern hemisphere) has been suggested for *E. nilssonii* and soprano pipistrelles, *Pipistrellus pygmaeus*, in Norway (Michaelsen et al. 2004), *Pipistrellus pipistrellus*, in Sweden (Ahlen et al. 2004), and *Eptesicus fuscus*, in North America (McAlpine et al. 2002). Bats may also benefit from favorable thermal conditions in buildings at higher elevations and may thus go beyond their normal elevational range. For example, a maternity colony of the rare eastern small-footed myotis, *Myotis leibii*, was found roosting in a high-elevation cabin above the previously known elevational limits for this species (O'Keefe and LaVoie 2011).

A similar argument can be made for hibernating bats in buildings. Strelkov (2002) made the point that the ability of some European bat species, such as *Nyctalus noctula*, to hibernate in buildings may have enabled them to overwinter in more northern regions than when using exclusively natural roosts. By doing so, *Nyctalus noctula* are closer to their breeding ranges when arousing from hibernation in spring, which gives them an advantage in terms of time and energy in relation to conspecifics that migrate to more southern areas. This could lead to the expansion of this species' geographic range northward.

14.4 Negative Consequences of a Synanthropic Lifestyle in Bats

14.4.1 Decreased Fitness Owing to Direct Threats

Humans The foremost direct threat for synanthropic bats are humans. The co-occupancy of buildings by bats and humans gives rise to various conflicts. Interestingly, many early papers that discuss bats in buildings deal largely with the eradication or control of bats roosting in buildings (e.g., Silver 1935; Daver 1953; Kunz et al. 1977; Barclay 1980). These papers were gradually replaced by descriptive papers about the biology of synanthropic bats and eventually by those focusing on conservation topics. Nonetheless, eradication of bats from buildings is an eminent, yet mostly undocumented, problem, in all regions of the world. Unfortunately, there are no data available on the number of bats killed each year by closing entrances to daytime roosts in buildings, by destroying roosts, or by fumigating or poisoning bats. In many countries, bats are considered pests or vermin. Therefore, eradication of whole colonies is commonly practiced. In some African countries, synanthropic molossids are consumed by humans as a delicacy (Goodman et al. 2008b), and the bats' distinct odor is regarded favorably from a culinary perspective (Allen et al. 1917), yet synanthropic bats as a form of bushmeat is rather the exception (Mildenstein and Tanshi 2015).

Buildings as traps Buildings may act as traps for bats, when bats that enter a building through open windows or structural gaps are unable to find the exit (Gaisler 1998). In Europe, *Pipistrellus pipistrellus* is most often trapped during autumn swarming (Pfalzer and Weber 2007; Kanuch et al. 2010). Bats may also be killed if they become trapped in wire mesh that is used to protect buildings from feral pigeons (König and Neumann 1996).

Predators Bats may also be killed by synanthropic predators. Some birds of prey, e.g., European kestrels and tawny and barn owls, specialize on bats that use buildings as roosts (Kovats et al. 2008; Lesiński et al. 2013; Mikula et al. 2013). Indeed, the high density of kestrels in Rome, Italy, is thought to be related to the abundance of feral pigeons, swifts, and bats (Salvati et al. 1999). In the Neotropics, great kiskadees, *Pitangus sulphuratus*, have been observed hunting *Myotis nigricans* and *Myotis albescens* when bats emerged from a building (Fischer et al. 2010). African goshawks, *Accipiter tachiro*, have attacked molossid bats, *Mops condylurus* and *Chaerephon pumilus*, near their roosts in buildings (Fenton et al. 1994). Synanthropic bats that fall to the ground or fly close to the ground may be captured and killed by domestic cats (Bruijn 1990; Ancillotto et al. 2013). Snakes and invertebrates have also been observed hunting bats in or at buildings (Esbérard and Vrcibradic 2007; Nyffeler and Knörnschild 2013).

In some cases, natural predators may have devastating effects on bats, in particular when they specialize on hunting emerging bats at the entrance of roosts. Synanthropic owls are especially efficient predators of bats in or around buildings. An effective protective measure is to install a small water hose above the entrance of a colony that is triggered by the presence of a perching predator (pers. communication K. Kugelschafter, Fig. 14.3). Since owls are puzzled by the sudden stream of water, they immediately leave the entrance without any harm done to the predator (pers. commun. K. Kugelschafter).

Pathogens Mühldorfer et al. (2012) reported that one-third of bat deaths in Germany were due to bacterial infections. According to this study, viral infections were less important as a natural cause of death, even though rabies infections are documented in some populations of synanthropic bats (O'Shea et al. 2012; Racey et al. 2013). Yet it is unknown to what extent bats suffer from rabies and whether disease dynamics are exacerbated in synanthropic species because of their specific choice of buildings.

14.4.2 Decreased Fitness Owing to Indirect Threats

Roosting in buildings, particularly in urban environments, may provide fitness benefits for bats. However, Coleman and Barclay (2012b) concluded that urban bats did not perform better in terms of body condition, reproductive rate, and number of weaned juveniles compared to rural bats. Indeed, bats seemed to perform best in the transition zone between urban and rural sites, and thus, the authors summarized that the process of urbanization may be universally detrimental to bats (Coleman and Barclay 2012b).

Fig. 14.3 Method to repel owls from the entrance of bat colonies in Germany. Water flows from the overhead water hose when the perching owl (*Strix aluco*) interrupts a light beam at the entrance to a colony of greater mouse-eared bats (*Myotis myotis*) (copyright Kugelschafter K)

Chemical pollutants Indirect threats for synanthropic bats are numerous, yet because of their subtle nature, it is more difficult to pinpoint indirect mortality risks. Chemical pollutants are likely an indirect threat for bats roosting in buildings (Mitchell-Jones et al. 1989; Bayat et al. 2014). Wood used in buildings is usually treated by chemicals such as chlorinated hydrocarbons to prevent rotting caused by fungi or insects. Bats roosting in buildings are in close contact with wooden structures and thus may be exposed to chemical preservatives such as lindane, pentachlorophenol, and pyrethroids (Racey and Swift 1986; Boyd and Myhill 1988; Mitchell-Jones et al. 1989; Shore et al. 1990, 1991; Bennet and Thies 2007). Most often, bats do not die immediately after contact with treated wood but instead suffer sublethal effects that cause, for example, immune suppression (Corrao et al. 1985; Clark and Shore 2001). Sometimes, bats are eradicated from buildings using poisons, and these poisons continue to persist so that bats may be exposed to toxic residues for extended periods after application. Poisoning is usually a gradual process that is exacerbated in temperate bats via the accumulation of toxic compounds in fat tissue and seasonal mobilization of these compounds during migration and hibernation (Mitchell-Jones et al. 1989; Bayat et al. 2014). Since the introduction of alternative bat-friendly chemical treatments of wood in buildings, mortality caused by chlorinated hydrocarbons has decreased markedly (Bayat et al. 2014), yet from a global perspective, the problem of slow poisoning of synanthropic bats in buildings remains an issue.

Parasites Patterson et al. (2007) found that bats inhabiting relatively permanent roosts, such as caves and buildings, carry more ectoparasites than bats that roost in temporal structures, such as leaves or tree hollows. Buildings may provide ectoparasites, e.g., streblid flies, bed bugs (*Cimex* spp.), or reduviid bugs (Triatominae; Reduviidae), an ideal substrate for egg laying and larval development. As female bats may be immunosuppressed during pregnancy, they may suffer from heavy parasite infestation during reproduction (Christe et al. 2000; Pearce and O'Shea 2007). The combined effect of inflammation and immune challenge may then increase oxidative stress and consequently reduce longevity in house-dwelling bats (Schneeberger et al. 2013; Lilley et al. 2014). Endoparasites are poorly studied in synanthropic bats. *Leishmania braziliensis* occurs in Brazilian house-dwelling bats, yet it is unknown whether roost choice and colony dynamics are different from those of conspecifics roosting in natural roosts and whether building roosts may impose a higher risk of contracting these parasites (Shapiro et al. 2013).

14.5 Consequences for Humans Sharing Buildings with Bats

14.5.1 Benefits of Sharing a Building with Bats

There are several direct benefits for humans when sharing buildings with synanthropic bats. Bats provide essential ecological services (e.g., pest suppression, pollination, seed dispersal) near houses, villages, and cities (Jones et al. 2009; Kunz et al. 2011; Ghanem and Voigt 2012). For example, synanthropic bats, such as molossids, feed on large quantities of insects that are vectors of human diseases, such as dengue, yellow fever, and chikungunya fever (Andrianaivoarivelo et al. 2006; Goodman et al. 2008b). In tropical and subtropical regions, bats are important seed and pollen dispersers. Orchards in house gardens may largely benefit from the cost-free ecosystem services provided by pollinating bats. Insectivorous bats have the ability to reduce insect herbivory in temperate forests (Böhm et al. 2011), tropical forests (Kalka et al. 2008), and tropical agricultural fields (Williams-Guillén et al. 2008; Maas et al. 2013). Thus, the presence of synanthropic bats comes with large, yet mostly unacknowledged, benefits to humans. Lastly, bats are an integral component of our natural heritage, and thus, they have intrinsic value (Soulé 1985).

14.5.2 Pathogen and Parasite Exposure

Viruses Bats inhabiting buildings may be reservoir hosts of viruses. For example, North American *Eptesicus fuscus* and Eurasian *Eptesicus serotinus* are both synanthropic species roosting in buildings, and they are known for their relatively high prevalence of rabies (Zorya 2002; O'Shea et al. 2012; Racey et al. 2013). In Dutch populations of *Eptesicus serotinus*, bats exhibited a 21 % seroprevalence for lyssavirus (Van der Poel et al. 2005), yet is unknown how many of these positive cases were infectious. In another Dutch study, 30 % of sampled bats that bit humans tested positive for European bat lyssaviruses (Takumi et al. 2009). Other synanthropic bat species may carry lyssaviruses, such as the molossid bats *Tadarida brasiliensis* or *Nyctinomops macrotis* in North and South America, or vespertilionid bats such as *Eptesicus furinalis* in South America (Clark et al. 1996; Uieda 1998; Passos et al. 1998; de Almeida et al. 2011; Favi et al. 2012) or nycterid bats such as *Nycteris thebaica* in Zimbabwe (Foggin 1988). In Kenya, SARS-like coronaviruses (CoVs) were identified in a *Chaerephon* spp. (Tong et al. 2009), and in South Africa, bat-derived CoVs that are closely related to the MERS-CoV were found in *Neoromicia capensis* (Corman et al. 2014). Frequent roost switching of synanthropic bats may increase the transmission risk of the rabies virus to humans (Ellison et al. 2007), particularly when humans try to evict bats from houses (Streicker et al. 2013). In general, precautionary measures should be taken when handling synanthropic bats: (1) Do not touch or handle bats without gloved hands, and (2) in case of a bat bite, immediately proceed to the appropriate facility for post-exposure prophylactics. A more detailed treatment of bat-related diseases is provided in Chap. 10 (Schneeberger and Voigt 2016).

Bacteria Bacterial infections are one of the primary causes of natural death in temperate bats (Mühldorfer et al. 2012), and many of the documented bacterial strains are relevant to human health. For example, bats may act as a reservoir for *Bartonella/Burkholderia* bacteria, which can be transmitted to humans via bed bugs (Saenz et al. 2013). Bat ticks, specifically *Argas vespertilionis*, collected from a human-inhabited building were documented to carry *Borrelia*, *Rickettisa*, and *Ehrlichia* species (Socolovschi et al. 2012). *Staphylococcus nepalensis* was detected in guano samples from mixed *M. myotis* and *M. blythii* summer roosts, and guano in or near buildings may pose a significant threat to human health (Vandzurova et al. 2013). To our knowledge, no direct infection of humans with bat-related bacterial strains has been described. Overall, synanthropic bats have the potential to transmit zoonotic diseases, yet as outlined by Mühldorfer et al. (2011), there is no evidence, at least for temperate zone bats, that they pose a greater health risk to humans than other wildlife species.

Parasites Besides bat-specific ectoparasites, bats may also carry generalist ectoparasites that could infect humans as well. For example, bed bugs (*Cimex* spp.) could possibly switch between bat roosts and rooms inhabited by humans (Pearce and O'Shea 2007). Bat ticks have been suggested to cause inflammatory responses in humans living in a building with bats in the attic (Labruna et al. 2014). Ticks associated with bats, and known to bite humans, may also be carriers of bacteria or viruses that can cause disease in humans. For example, *Carios kelleyi* collected from residential and community buildings in Jackson County, Iowa, tested positive for *Rickettsia* (Loftis et al. 2005). In addition, some endoparasites are threats to human health, yet many depend on an invertebrate host as a vector for transmission to humans. For example, in Brazil, *Leishmania braziliensis* occur in some synanthropic bat species that serve as a reservoir host for leishmaniasis but require sand flies as a vector (Shapiro et al. 2013).

Fungus Environments soiled with large accumulations of guano may harbor *Histoplasma capsulatum*, a fungal pathogen that causes histoplasmosis. When roosts in attics, roofs, and other rooms are not cleaned on a regular basis, guano accumulates creating a greater risk to humans (Bartlett et al. 1982; Martins et al. 2000). Humans can develop histoplasmosis after inhaling the microscopic spores of *H. capsulatum*, often while participating in activities that disturb a heavily contaminated environment. While histoplasmosis is rarely fatal, infections in individuals with weakened immune systems can become severe (Martins et al. 2000), yet it is questionable that infections by *H. capsulatum* can be traced back to bats.

14.5.3 Noise, Odor, Dust, and Activity

Although echolocation calls emitted by most bats in open space are not audible to humans, many social vocalizations of bats are noticeable because they are typically below the 20 kHz auditory threshold of humans. These vocalizations may be particularly evident at times of the year when pups use contact calls to attract their returning mothers. Such vocalizations combined with noises caused by terrestrial locomotion of bat inhabitants, e.g., molossid bats moving through small crevices below tin roofs, can be a nuisance for human inhabitants. In addition, humans sometimes complain about bat-related odors and dust (Razafindrakoto et al. 2011).

14.5.4 Harmful Bats

Bat feces is suggested to have antigenic properties, causing skin rashes in susceptible humans (Alonso et al. 1998), yet detailed studies are lacking. To our knowledge, there is only one bat species worldwide that could be directly harmful to humans. The common vampire bat, *Desmodus rotundus*, consumes mammalian blood but is restricted to Latin America. Although this species feeds primarily on livestock animals, e.g., cattle (Delpietro et al. 1992; Voigt and Kelm 2006), vampire bats may feed on sleeping humans not protected inside buildings (Schneider et al. 2001; Carvalho-Costa et al. 2012). Though vampire bats are not known to inhabit occupied buildings, in some areas of South America, these bats inhabit abandoned buildings next to occupied houses (Mialhe 2013). Besides the potential of contracting rabies via a bite, humans can suffer from inflammation, secondary infections, and blood loss. Overall, humans are not a regular victim for vampire bats.

14.5.5 Destruction of Buildings Caused by Bat Excreta

Bats may inhabit buildings over many years, or even centuries, and accumulated feces and urine may cause severe damage to buildings. For example, bat guano was the cause of damage to some buildings of the UNESCO World Heritage Centre—Angkor monuments in Cambodia. Apparently, salts in excretions of bats are eroding the sandstone of some ancient buildings (Hosono et al. 2006). In most cases, structural damage can be prevented by removing accumulations of guano. Plastic sheets can be placed over exposed structures to protect them and facilitate the removal of urine and guano; in addition, wooden boards placed directly under roosts may also be helpful in collecting bat excreta from roosts inside buildings.

14.6 Conservation of Bats in Buildings: Avoidance, Mitigation, and Compensation

The protection of synanthropic bats and their roosts should occur in a tri-level hierarchical pattern. First, it should be determined whether bat roosts can be preserved, e.g., left untouched, even when construction work is carried out near the roost. Second, if construction work affects the roost, developers and architects should mitigate the impact on the bat colony (mitigation). Lastly, if bat roosts are going to be lost, when, for example, barns are converted into apartments (Briggs 2004), appropriate compensation measures should be practiced in order to offer bats an alternative roost. Although this general approach may not be applicable in all countries, particularly when the legal framework is lacking, we will elaborate on it in the remainder of the chapter.

Conservation guidelines for bats in buildings have been formulated in various countries, including those from the European Union (Table 14.1; Marnell and Prsetnik 2010). Conservation networks (Kingston et al. 2016, Chap. 16) could use these and our recommendations to develop further region-specific guidelines for the protection of local synanthropic bats.

14.6.1 General Considerations for the Conservation of Bats in Buildings

Monitoring of colonies Monitoring of bat colonies, particularly maternity colonies, in buildings needs to be conducted with appropriate care (Kunz and Reynolds 2003). In some countries, it is legally forbidden to disturb bats in their roosts, particularly during the maternity period. Kunz and Reynolds (2003) suggested conducting evening emergence counts at roost exits to monitor maternity colonies without disturbing bats.

Table 14.1 List of Web-based resources pertaining to the conservation of synanthropic bats (sorted alphabetically according to continent or country)

Country	Web address
EU	http://www.eurobats.org/sites/default/files/documents/publications/publication_series/pubseries_no4_english_2nd_edition.pdf
France	http://www.sfepm.org/chiropteres.htm
Australia	http://ausbats.org.au/#/bats-in-your-house/4569171536
Latin America	http://www.relcomlatinoamerica.net/images/PDFs/PROTOCOLO.pdf
Germany	http://www.nabu.de/tiereundpflanzen/saeugetiere/fledermaeuse/aktivwerden/01506.html
Ireland	http://www.batconservationireland.org
Italy	http://biocenosi.dipbsf.uninsubria.it/chiroptera/
Netherlands	http://www.vzz.nl
Russia	http://zmmu.msu.ru/bats/popular/v_dome.htm
UK	http://www.bats.org.uk/pages/bats_and_buildings.html
UK	http://www.bedsbatgroup.org.uk/wordpress/?page_id=3429
UK	http://jncc.defra.gov.uk/page-2861
UK	http://www.naturalengland.org.uk/ourwork/regulation/wildlife/species/bats.aspx
USA	http://www.conservewildlifenj.org/protecting/projects/bat/buildings/
USA	http://www.nature.nps.gov/biology/wns/assets/docs/2012BatsInBuildingsWebinarOdegard.pptx

Life stages of bats For effective protection of synanthropic bats, it is crucial to understand the purpose of the buildings being used as roosts by bats. We have outlined several possibilities for why bats use buildings. Since bats may be particularly vulnerable during their reproductive period and during hibernation, roosts that are used by bats during these life stages are of prime concern for conservation efforts. The central recommendation for such roosts is to leave them untouched, unless gradual deterioration of the building may destroy the roost.

Human occupancy Usually, disturbance of synanthropic bats by humans is detrimental to colonies. For example, de Boer et al. (2013) showed for the Netherlands that hibernacula in buildings were more suitable for bats when disturbance by humans was low. However, it should be noted that some studies report that synanthropic bats tend to leave roosts when humans no longer use buildings, possibly because buildings are no longer heated (Frafjord 2007). In Poland, Sachanowicz and Wower (2013) found evidence that the gradual deterioration of buildings caused an impoverishment of species in the local assemblages of attic-dwelling bats. Therefore, human occupancy of buildings may be a benefit in some circumstances and a disadvantage in others, depending on the species involved and the specific life stages.

Interior of roosts The size and spatial structure of building interiors affects the occupancy by synanthropic bats. For example, the availability of sufficient space and optimal microclimatic conditions seem to be beneficial for attic-dwelling bats, such as the endangered Townsend's big-eared bat *Corynorhinus townsendii*

(Betts 2010) and Rafinesque's big-eared bat, *Corynorhinus rafinesquii* (Loeb and Zarnoch 2011). In addition to roost compartments, relatively higher ambient temperatures in roost interiors are also relevant for bats inhabiting buildings (Entwistle et al. 1997). *Eptesicus fuscus* prefer old buildings with galvanized (tin) roofs that are also taller than surrounding buildings, most likely because of higher temperatures and wider temperature gradients in these buildings (Williams and Brittingham 1997). For some hibernating bats, the size and number of hiding places may contribute to the quality of hibernacula in buildings.

Exterior of roosts Synanthropic bats not only depend on suitable roosting interiors, but also depend on the quality of the surrounding environment, e.g., for foraging or drinking. Suitable roost entrances are critical for some bats, particularly for fast-flying species with a low ability to maneuver (Neubaum et al. 2007). For example, *Nyctalus noctula* roosting in buildings preferred roosts that were located at the top floors (Bihari 2004; Cel'uch and Kaňuch 2005). Molossids, e.g., *Chaerephon ansorgei*, and vespertilionids, e.g., *Neoromicia capensis*, that inhabit crevices or narrow spaces under roofs are capable of landing and crawling through narrow roost entrances, whereas horseshoe bats, e.g., *Rhinolophus clivosus*, and slit-faced bats, e.g., *Nycteris thebaica*, require an opening large enough to fly through since they usually do not crawl (Monadjem et al. 2010). Other species, such as *Pipistrellus pipistrellus*, are generalists with respect to their roost preference, i.e., they do not prefer specific structural attributes of buildings (Jenkins et al. 1998). It is also noteworthy that some species may require several roosts in separate buildings to establish a stable colony, e.g., greater horseshoe bats, *Rhinolophus ferrumequinum* (Maltagliati et al. 2013), eastern pipistrelles, *Pipistrellus subflavus* (Whitaker 1998), and *Eptesicus fuscus* (Ellison et al. 2007; O'Shea et al. 2012).

Additional landscape elements, such as vegetation and water sources, have been suggested to promote bat populations in cities (Neubaum et al. 2007). Trees in the vicinity of roosts were beneficial for pipistrelle bats, *Pipistrellus pipistrellus*, not only as foraging grounds but also as a protection against aerial predators, thus enabling bats to increase their nocturnal foraging activity substantially by emerging earlier from their roost (Jenkins et al. 1998). Brown long-eared bats, *Plecotus auritus*, preferred buildings situated close to woodland and water (Entwistle et al. 1997; Moussy 2011).

Illumination of buildings at night by streetlamps reduces the quality of roosts for some bats. For example, European *Rhinolophus ferrumequinum*, *Myotis emarginatus*, *and Myotis oxygnathus* emerged later at sunset from roosts when buildings were illuminated. Also, body mass and forearm length were smaller in juveniles from illuminated buildings than in those from not illuminated. In the worst case, roosts are abandoned after direct lighting of the buildings in which the roost is located (Boldogh et al. 2007).

Eviction of bats from roost Eviction of bats from houses is practiced worldwide, yet it is against the law in some countries. The corresponding authorities may grant concessions if there is no alternative to the exclusion of bats from roosts. Yet, in many countries, it is a legal requisite that appropriate measures are practiced to compensate for the loss of a roost. The permanent closure of roost exits or the destruction of a roost should only be considered during times when bats are not using the roost, e.g., outside the reproduction or hibernation period. Otherwise, bats may be trapped and killed, which is against animal welfare. If roosts are destroyed or closed, bats may switch to alternative roosts (Neilson and Fenton 1994). After eviction of *Eptesicus fuscus* from buildings, females produced fewer offspring at alternative sites, even though foraging behavior remained constant (Brigham and Fenton 1986). Relocation of bats to nearby habitats usually fails because bats will return to their original roost in most cases. Lastly, the permanent eviction of bats from roosts may increase the frequency of roost switching. In the case of species with a high prevalence of rabies infections, it is predicted that the rabies transmission risk may increase due to more, and possibly undirected, movements of evicted bats around buildings (e.g., *Eptesicus fuscus*, Streicker et al. 2013). Therefore, roost closures might have unforeseen and unwanted side effects for public health.

14.6.2 Avoiding or Mitigating Roost Losses in Buildings

Roosts are key resources for bats since many species are limited by roost availability (Kunz 1982; Kunz and Lumsden 2003). Therefore, a prime conservation effort should be the protection of existing roosts and possibly the enhancement of their quality. If private or commercial development of buildings is an inevitable conflict with synanthropic bats, appropriate measures should be practiced, particularly when the species is endangered and/or protected.

Reduction of human disturbance Disturbance of bat roosts in buildings can lead to a variety of outcomes, ranging from direct effects when people disturb building roosts to indirect effects of noise and light pollution. Bats seem to adjust quickly to noise, yet as Rowse et al. (2015) point out, some species may be quite sensitive to artificial light. For example, *Pipistrellus pipistrellus* are quite tolerant to artificial light during foraging, but altered their emergence behavior when exposed to different light intensities at their daytime roost (Down et al. 2003). Directing artificial light at roost entrances may have a negative impact on bats roosting in buildings (Boldogh et al. 2007). Adjusting the regime of artificial light near a colony and reducing the light spill from neighboring buildings or streetlamps should be considered to improve the quality of roosts in buildings.

It is important to recognize that human visits to hibernacula of bats in buildings might cause bats to arouse from hibernation, a process that is energetically costly and causes bats to deplete their fat depots which increases the risk of starvation (Speakman and Thomas 2003). Therefore, it is necessary to cease visitations to known hibernacula to minimize impacts on hibernating bats.

The impact of disturbance caused by structural work in buildings, e.g., renovation of roof structures or attics, can have severe consequences for synanthropic bats. Indeed, colonies will abandon roosts because of this disturbance. To minimize these negative impacts, construction work should only take place during the annual period when bats are not using the roost. For example, renovation of attics used by bats as maternity roosts should only occur after juveniles fledge or when colony members leave the roost to hibernate in another location. Minimizing disturbance is also vital for protecting hibernacula, and construction work at these sites should not be conducted during the hibernation period.

Conservation of smaller-sized roosts Reduction of the size of bat roosts inside buildings might be acceptable if the only alternative is the complete loss of a roost. For example, attics or barns are sometimes converted to apartments or houses, respectively. If bats are roosting in an attic or barn, a small part of it could be separated from the space used by humans and this smaller space could be designated for the exclusive use by bats. However, it should be noted that many bat species roosting in attics or barns prefer large and complex structures with some variation in microclimate conditions. A decrease in size and structural complexity of the roost space may lead to the gradual decline in colony size and possibly complete loss. Therefore, a reduction in roost size may best be accompanied by the provision of new artificial roosts that are suitable for the specific bat species (Figs. 14.4 and 14.5; Kunz and Reynolds 2003).

Fig. 14.4 Artificial bat roost on the exterior of the Leibniz Institute for Zoo and Wildlife Research building in Berlin, Germany. *Nyctalus noctula* use the roost during autumn

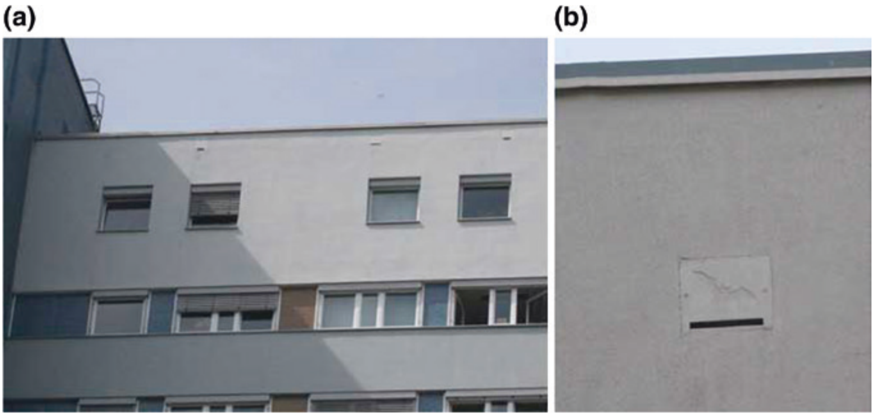

Fig. 14.5 Artificial bat roosts embedded into the external insulation layer of a renovated public building in Berlin, Germany: **a** row of artificial roosts within the top floor of a seven-story building; **b** detail of a single artificial roost (the horizontal exit is at the base). Such roosts are suitable as hibernation sites and stopover sites during migration for noctule bats, *Noctula noctula*, in Europe, yet they may not host as many individuals as buildings before renovation

14.6.3 Compensating for Lost Roosts

Sometimes it is inevitable that roosts in buildings are lost. The addition of artificial bat boxes near previously occupied buildings can successfully compensate in some instances. For example, colonies of *Pipistrellus pygmaeus* and *Plecotus auritus* and various other species throughout Europe benefited from artificial roosts when the original roost was destroyed (Anonymous 2006; Beck and Schelbert 1999). Artificial bat roosts were also provided for and accepted by South American *Molossus molossus* when roosts in buildings were destroyed (Alberico et al. 2004). In North America, *Eptesicus fuscus*, and *Myotis lucifugus*, will occupy artificial bat boxes installed at buildings that formerly housed colonies (Brittingham and Williams 2000). For example, the Bat House Research Project in the Kruger National Park, South Africa, has recently provided new accommodation for bats in the Letaba Rest Camp in an effort to help identify the most effective way to remove bats from buildings within the park (http://www.krugerpark.co.za/krugerpark-times-2-11-bat-accommodation-19864.html). Similar attempts to provide alternative roosting structures for synanthropic bats have been successful in the USA; for example, artificial roosts have been built on the campus of the University of Florida to host populations of *Tadarida brasiliensis* and other native bats (https://www.flmnh.ufl.edu/index.php/bats/home/).

These success stories should not imply that roosts in building are replaceable by artificial structures and that bats will readily occupy artificial roosts. Sometimes, for unknown reasons, bats avoid artificial roosts in buildings completely. Therefore, protection of existing roosts should be considered prior to attempting the use of artificial roosts.

14.6.4 *Loss of Roosts Due to Demographic Changes in the Human Population*

Demographic changes in human populations of many countries are turning rural areas into areas nearly devoid of humans. As a result, buildings are abandoned and, due to a lack of maintenance, deteriorate over time. Shortly after abandonment, many synanthropic bat species benefit, likely due to the reduced disturbance by humans. Deserted buildings may provide new roosting structures for bats, e.g., for *Hipposideros nicobarulae* in Myanmar (Douangboupha et al. 2012). Yet in the long run, synanthropic bats may vanish from these sites when buildings deteriorate (Sachanowicz and Wower 2013). Another effect of demographic changes involves movement and thus concentration of people in urban areas. Following this, previously unused buildings, even in industrial areas, or unoccupied space under the roof of buildings are converted into houses or apartments to host the influx of people in cities. This may cause losses of roosting opportunities for synanthropic bats. In China, like in many Asian countries, a vast number of old buildings are demolished during the process of modernization and this reduces the density of roosts significantly for synanthropic bats (Zhang et al. 2009).

14.7 Examples of Good Practice

14.7.1 *Example 1: The Outreach Program for the "Bat-Friendly House"*

To conserve synanthropic bat species, education appears to be the prime method to protect bat roosts in buildings. Kingston (2016, Chaps. 17 and 18) address various outreach approaches. Here, we focus on a specific German-based conservation program called "bat-friendly house." Directed by a consortium of nonprofit organizations (spearheaded by the "Naturschutzbund" Germany) and federal and local authorities and bat conservationists, the program has created a "Bat-Friendly House" award for owners who protect bat colonies in their buildings. The major goal of this program is to support populations of synanthropic bats by maintaining or even enhancing their roosts and to involve local people in the protection of bats. Several hundred houses have been deemed bat-friendly in the federal states of Hessen, Schleswig-Holstein and Northrine-Westfalia and others in Germany. The award ceremony is usually accompanied by a press campaign to raise awareness about the conservation of bats that use building as their roosts. Similar programs have been initiated in other EU countries.

14.7.2 Example 2: Renovated Buildings Designated for Bat Conservation Purposes

There are many examples of buildings that were renovated successfully to mitigate the human–bat conflict or to protect endangered bats. The details of the vast majority of these cases have not been documented or published. Yet, it is encouraging to read about some of the examples on Web pages or in the gray literature of nongovernmental organizations (Table 14.1). The EUROBATS publication, available at www.eurobats.org, provides examples of successful projects throughout Europe. Many of these examples underline that the details of specific conservation efforts depend largely on the biology of the target bat species and on local circumstances, ranging from the building in question, the overall legal framework, and the funding agencies and the authorities and persons involved. We have summarized some general features in the next section that might be relevant for many synanthropic bats, but we cannot provide a comprehensive overview of all projects. We have also refrained from repeating case studies that have already been described in detail at other places. Instead, we focus on a single example that we consider successful because it combines efficiently the practical aspects of protecting a building for an endangered bat species, preservation and enhancement of suitable habitats, and a community-based outreach program to facilitate the acceptance and thus continuation of the project beyond the funding period.

Protection of the last maternity colony of greater horseshoe bats, *Rhinolophus ferrumequinum,* in Germany According to surveys over the past decades, populations of greater horseshoe bats, *Rhinolophus ferrumequinum*, are on the decline throughout Europe (Ransome and Hutson 2000; Dietz et al. 2009; Spitzenberger et al. 2010). Although some parts of southern Germany were inhabited previously by this species, today they are virtually absent from Germany except for a maternity colony found in 1992 in Hohenburg, a small village located in northeastern Bavaria adjacent to a large military training area. Because of its rarity, this species is categorized as "Threatened by Extinction" in the national red list of mammals for Germany.

The colony occupied a house and adjacent farm buildings that were built in the sixteenth century. Since the 1980s, the buildings have not been inhabited or used by humans (Fig. 14.6). Thus, the complex deteriorated and was nearly to the point of collapse when the colony was discovered. In 1992, there were 21 adults, yet it is unknown how large the colony had been before its discovery.

After initial monitoring of the bats in the colony and their feeding habits, it was decided in 2011 to apply for a grant from the European Union which supports biodiversity projects. Since the funding scheme required complementary funding sources, the applicants, namely the "Landesbund für Vogelschutz e.V.," a German NGO devoted to protecting national biodiversity, contacted additional partners, such as "Bayerischer Naturschutzfonds," "Bundesanstalt für Immobilienaufgaben," and "Naturpark Hirschwald," to reach the critical financial needs for achieving the conservation plan.

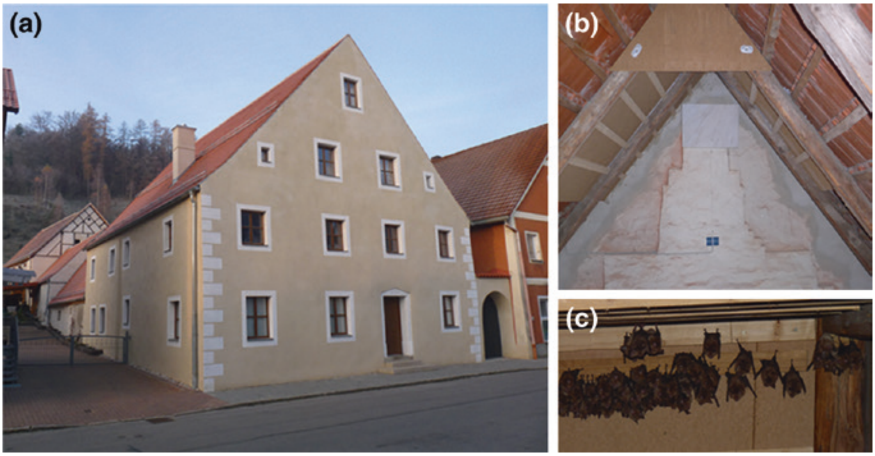

Fig. 14.6 Building complex that hosts the last maternity roost of the greater horseshoe bat, *Rhinolophus ferrumequinum*, in Germany (**a**). Bats most often use the attic of the largest backyard building (**b**). The attic ceiling functions as a heat trap where warm, upward moving air is trapped; this is the preferred roosting area for the colony (**c**)

Based on an initial investment made by the German government in support of small and intermediate companies during the 2011 bank crisis, it was first decided to renovate the complex of buildings after bats left for hibernation in nearby caves. Developers were faced with the difficult task of renovating a building complex that was protected by law, while at the same time keeping the roosting requirements of greater horseshoe bats in mind. The majority of space inside the building complex was designated for the exclusive use by bats. The ground floor level of the main buildings was transformed into an education center and some office space for the project coordinator. The fact that several attics and rooms with variable microclimatic conditions were available to the colony likely contributed to the success of the project. This is consistent with observations of roost use by greater horseshoe bats elsewhere. For example, Maltagliati et al. (2013) pointed out that the largest nursery colony of *Rhinolophus ferrumequinum* in Italy uses several buildings. The Hohenburg house was carefully modified to include some further beneficial structures for bats. For example, workers built a so-called heat dome inside the attic where warm, upward moving air is trapped in a structure that is used by bats as a roosting site (Fig. 14.6b, c). Furthermore, they created a 1-m^2 pool of water (3 cm depth) at which bats may drink. Finally, roost exits were constructed in a way that prevents predators, e.g., stone martens and domestic cats, from entering the building.

Second, it was understood that horseshoe bats would not survive if adjacent habitat structures degenerate by forest succession. Therefore, they designed a strategy to protect and indeed improve habitat structures for *Rhinolophus ferrumequinum*, a strategy that has proven successful for other synanthropic bats as well

(Murphy et al. 2012). Accordingly, a strategic plan was developed to protect foraging habitats and enhance the quality of landscape elements. Efforts are currently underway to convert forests into so-called Hutewald, which is an extensive forest used by livestock as pasture that resembles a landscape park. Furthermore, nearby hibernacula in natural caves were protected by fences to minimize disturbance of roosting bats.

Finally, the project includes an outreach program in which local people are informed about the progress of the project and engaged in fulfilling the working plan. The education center is equipped with monitors to provide real-time views into the bat colony. Project workers explain the goals of the project and show visitors the emergence of colony members at dusk. By using bat detectors and by direction observation, visitors learn firsthand about the biology of this fascinating species. Lastly, interested people might also visit the Web page of the project and observe bats using the Webcam (http://www.lbv.de/unsere-arbeit/life-natur-projekte/life-projekt-hufeisennase.html). Local hotels and restaurants in Hohenburg and adjacent villages have benefited from tourists and bat enthusiasts who come to this area for the single purpose of learning more about the Hohenburg colony of *Rhinolophus ferrumequinum*.

Since its discovery, the size of the colony has increased fourfold, numbering 94 adult *Rhinolophus ferrumequinum* and 37 juveniles in 2013 (pers. comm. Rudolf Leitl). Currently, efforts are underway to provide appropriate roosting structures in buildings and protected hibernacula in the nearby area to offer a suite of habitats for the expanding Hohenburg colony with the ultimate goal to establish further colonies in the larger region.

14.8 Synthesis and Outlook

Synanthropic bats are, by definition, in close contact with humans. Although this contact bears some risks to both humans and bats, it also provides opportunities to promote bat conservation. Practical aspects regarding the conservation of synanthropic bats in buildings, such as how to construct a new roost or enhancement of an existing building roost, should be one part of conservation efforts. From our point of view, it is equally important to engage in outreach programs and communicate with building owners about the conservation value of synanthropic bats (see also Kingston et al. 2016). With respect to research directions, we identify the following questions that need to be addressed:

1. What sensory cues do bats use to explore buildings as potential night or day roosts?
2. What are the differences in microclimate between natural and building roost sites, particularly in tropical and subtropical regions?
3. Is use of building roosts a learned behavior? Do local populations establish a tradition of inhabiting buildings?

4. Is swarming behavior unique to European bats?
5. Are there differences in the way bats use buildings between areas or continents where buildings have been in place for many centuries compared with areas where humans have only built houses recently.
6. Do tropical and subtropical bats also use buildings for extended periods of torpor, similar to hibernation of temperate zone bats?
7. What is the selective benefit for synanthropic bats inhabiting roosts in buildings compared with conspecifics inhabiting natural roosts? Why do some species commonly hibernate in buildings and others do not (see also Rintoul and Brigham 2014)?
8. Do tropical and subtropical bats exhibit similar expansions of geographic ranges when thermal benefits of using buildings as roosts are not the predominant driving benefit?
9. Is it possible to estimate the monetary value of ecosystem services provided by synanthropic bats?
10. To what extent have the geographic ranges of synanthropic bats changed in response to the coinhabitation of buildings?

Apart from these basic research questions, we need to engage in larger conservation efforts to protect synanthropic bats in developing countries, taking into account their ecological and economic value. Synanthropic bats face an uncertain future in many temperate countries due to political measures and specific programs to improve building standards, e.g., building modernization in the European Union that involves increased insulation of exterior walls has led to the large-scale eviction of synanthropic bats from buildings. We also see a strong incentive to coordinate conservation efforts to protect populations of synanthropic bats. Bats that live in the same buildings as humans could be ambassadors for the conservation of bats if other successful outcomes are replicated and publicized to a general audience. We conclude that synanthropic bats coinhabiting buildings with humans may provide good opportunities to teach humans in both urban and rural environments about wildlife species, particularly bats.

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