Biology, Habitat, and Management of Bed Bugs

This article discusses bed bug biology and habitat and describes how an Integrated Pest Management program for bed bugs should include identification and surveillance along with various cultural, mechanical, and chemical control options.

Bed bugs are blood-sucking insects of the order hemiptera. Unlike mosquitoes or ticks, bed bugs do not transmit diseases. However, bed bug bites can cause allergic reactions, secondary bacterial infections (such as impetigo, ecthyma, and lymphangitis) and mental health issues (such as anxiety and insomnia).

In recent years, pest control businesses have increased their bed bug control services. According to the 2018 Bugs Without Borders survey conducted by the National Pest Management Association, the top three places where pest professionals have treated bed bugs are single-family homes, apartments, and hotels/motels. In addition, bed bugs are frequently found in nursing homes, schools and daycare centers, offices, college dorms, hospitals, and public transportation.

**Part 1: Biology of Bed Bugs**

Bed bugs undergo incomplete metamorphosis, where the immature form or nymph resembles the adult, only smaller and not sexually mature (see Figure 1). Eggs are white and oval shaped (approximately 1/16 of an inch long), commonly laid in bed bug resting nests such as cracks and crevices in walls, floors, beds, and furniture. At room temperature, nymphs emerge from eggs within 5 to 10 days.

Figure 1. Bed bug life cycle. Illustration: Garo Goodrow (Penn State), originally for North Carolina State University

Nymphs undergo five stages of development called instars, growing larger with each molt, which can last for several weeks, under favorable conditions, or up to a year when temperatures and host availability are low. One blood meal is required between instars and it can take about 3 to 10 minutes, but nymphs can live for several months without one. Nymphs range in size from 1/16 (first instar) to 1/6 of an inch long (fifth instar) and they are yellowish-white in color.

Nymphs and adults have a sucking mouthpart, shaped like a straw, called a "stylet" which is held close beneath the head and thorax when not in use, and swung down into position before feeding. Adults are about 1/4 inch long, oval, reddish-brown, and wingless. They have a flat body with long, slender legs and antennae. Male and female adults become engorged in about 10 to 15 minutes; they usually feed every 3 to 4 days, but they can live over a year without feeding. Females require blood meals to lay eggs. Each female can lay up to 5 eggs per day and about 500 eggs in their lifetime.
Bed Bug Species

Bed bugs are members of the Cimicidae family. In the United States, approximately six species of bed bugs feed on mammals and birds. *Cimex lectularius* is the most common bed bug in Pennsylvania, as well as in the rest of the United States. It is known as the "common bed bug" and prefers to feed on humans, but it can also feed on dogs, cats, birds, and rodents (see Figure 2). The Eastern bat bug, *Cimex adjunctus*, is also found in Pennsylvania. Bat bugs are ectoparasites of bats and birds (see Figure 3). Ectoparasites live on the outside of the host. They are commonly found in the attic or walls when bats are present. Bat bugs migrate if they cannot find their preferred host and they readily bite people. The other species of bed bugs are not typically found in Pennsylvania.

Bed Bug Behavior and Habitat

Bed bugs hide during the day and avoid places with movement and light during the night. They use carbon dioxide, warmth, and moisture to locate their hosts. Bed bugs tend to feed on exposed areas of humans such as the face, neck, arms, and hands. Humans are not disturbed while bed bugs are feeding because bed bugs inject anticoagulants and anesthetic through their saliva, which usually leads to an allergic reaction in the form of a colorless wheal, welt, or lump at the bite location. After feeding, bed bugs defecate semisolid and sticky materials that leave reddish-black spots on mattresses or nearby furniture (see Figure 4). Spots and fecal material odors are good clues to the presence of bed bugs.

Part 2: Integrated Pest Management (IPM) for Bed Bugs

The time it takes to control bed bug infestations in buildings and residential houses varies depending on the infestation level, complexity of the environment, cooperation from the occupants, and thoroughness of the treatment procedures. IPM is defined as using a combination of approaches, including cultural, mechanical, biological, and chemical, in order to provide control.

Scientific research of bed bug control in apartment buildings has shown that IPM programs (using mechanical and chemical control) were more effective and efficient when compared to a chemical approach alone. In addition, IPM programs require fewer pesticide applications to control bed bugs in residential buildings. Surveillance is an important tool for a successful IPM program for bed bugs. It is used to detect or evaluate infestation levels before, during, and after treatments of IPM programs.
Identification and Surveillance

Proper identification is important before starting any bed bug treatment because client-made identifications are often unreliable. Bed bugs are sometimes mistaken for ticks, fleas, cockroaches, carpet beetles, or other household insects. Furthermore, bites should never be used for diagnosis because several household pests are known to bite humans, and bite reactions vary among people.

Bed bug surveillance is important to estimate the infestation level before control and the treatment efficacy after control. The following are types of bed bug monitoring methods.

**Visual Inspection** Visual inspections have a detection rate of 72 percent. Professionals perform these inspections to determine infestation areas and levels of infestation before starting treatment for bed bugs or to evaluate efficacy after treatment. However, brief visual inspections can be done to detect early infestations by properly trained interns, staff, or housekeepers (in hotels). Inspectors should search for reddish-black spots, eggs, shed "skin" of larval bed bugs, and immature and adult bed bugs in their habitat near human resting areas such as beds, couches, and recliners (see Figure 5). In addition, the sweet and musty odor produced by bed bug waste is characteristic of a moderate to high level of infestation.

![Figure 5: Bed bug visual inspection. Illustration: Garo Goodrow, Penn State](image)

**Bed Bug Sniffing Dog Inspections** Bed bug sniffing dogs can detect bed bugs with a 97 percent rate of accuracy. They can detect all bed bug life stages in low and high infestations. Dogs are trained by the association of reward systems to detect bed bug odors. They search on the most common areas where bed bugs can be found. However, dogs are directed by their handler if they miss locations. When dogs detect bed bug odors, they alert their handler who verifies by visual inspection. Dogs are more efficient than people because dogs detect bed bugs in areas with no sight such as inside walls, behind baseboards, and in furniture.

![Figure 6: Interceptor cups used to trap bed bugs. Photo: Parker Goodrow, friend of Penn State](image)

In addition, interceptor cups are also used to evaluate treatment efficacy and to protect beds from bed bugs. To maximize protection, it is important that beds not touch walls or any nearby furniture. Dust ruffles or any bedding that touches the floor will also keep the interceptors from serving as protection from bed bugs.

**Bed Bug Monitors** Interceptor cups, which have a detection rate of 89 percent, are the most common devices. Interceptor cups are based on the principle that bed bugs are not very good at climbing slippery, vertical surfaces. Cups are plastic dishes large enough to contain a bed post, with an outer "moat" designed to catch and retain bed bugs (see Figure 6). Cups are also called "pitfall traps for bed bugs." They can be placed under bedposts, anywhere under the bed, and under sofas and furniture where bed bugs may hide. Also, cups can be placed in bathrooms, kitchens, hallways, or anywhere desired because bed bugs are mobile and may be found throughout the home.

![Figure 7: Insect monitor cards used to catch bed bugs. Photo: Garo Goodrow, Penn State](image)

Insect monitor cards, also known as "sticky and glue cards," can be used to monitor the presence and movement of bed bugs in narrow and hard-to-reach locations such as behind picture frames, mirrors, or headboards (see Figure 7). Interceptor cups and insect monitor cards are passive monitors. In contrast, active monitors are electronic devices that use carbon dioxide (CO$_2$) and heat to attract and trap bed bugs (see Figure 8). These devices have the potential, especially in the absence of a host, to detect bed bugs that would normally remain hidden in empty apartments, empty school classrooms, or other locations. They are used by pest control companies to monitor bed bugs during treatment. In addition, interceptor cups containing CO$_2$ or pheromones are considered active monitors. It is best to use CO$_2$ traps over weekends or holidays in school or work sites. Dry ice can be used to produce the CO$_2$.
Visual Inspection and Interceptors When both visual inspection and interceptors are used for monitoring bed bugs, the detection rate increases to 99 percent. This technique is considered the most cost-effective method for performing building-wide inspections for bed bugs.

Cultural Control

Public awareness is a significant factor in the bed bugs spread throughout the country. Education of staff and residents in multifamily housing regarding bed bug biology and behavior, and what actions to take is an important component of any IPM effort. Usually, new bed bug infestations begin when people take infested articles home. If second-hand furniture is acquired, inspect it before bringing into buildings, especially beds or mattresses. Travelers can also transport bed bugs in luggage or on clothes. To avoid this, travelers should check behind headboards, under sheets, and in mattress seams and tufts at places where they stay. Also, they should inspect their luggage before carrying it back into their homes and wash and dry all clothes with hot water and hot air immediately upon return. If furniture is discarded due to bed bugs infestation, render it unusable before placing in a dumpster or landfill so that someone does not unknowingly bring infested items home.

Mechanical Control

Mechanical control is important in IPM programs of bed bugs because several objects in the home cannot be properly treated with insecticides. Mechanical control is not toxic, is environment-friendly, and does not require a re-entry interval (time that must pass between the pesticide application and the time that people can return to that area without protective clothing and equipment). However, mechanical control does not have a residual effect so re-infestation of bed bugs can occur.

Laundering and Drying with Heat Laundering with hot soapy water and drying with heat can be used to kill bed bugs on sheets, blankets, curtains, pillows, clothes, and any other objects that can be thrown into a washer and dryer. As an alternative, dryers alone can kill bed bugs when used at a high temperature for 15 to 30 minutes. Temperatures of 131°F or above are lethal to all bed bug stages. Laundering in cold water and drying at lower temperatures might not kill bed bugs.

Vacuuming Vacuuming can be used to remove nymphs, shed "skins," and dead bed bugs. Using a vacuum cleaner by itself is not effective because bed bug eggs are rarely picked up and most bed bug adults cannot be reached. Vacuum thoroughly every day and reach all possible areas (top, bottom, and sides) of the objects vacuumed. Empty the vacuum cleaner immediately. If the vacuum has a bag, enclose it in a plastic bag and seal it before discarding.

Steam Steam treatment can be used on objects that can not be treated with insecticides, such as couches, recliners, beds, toys, etc. (see Figure 9). Steamers vary in price, heating, and operating time. Triangular and rectangular heads are common. Small steam heads and those equipped with brushes should be avoided as the steam pressure and bristles may inadvertently dislodge bed bugs from the surface material onto the floor. However, these may be appropriate when the area is too small for a larger head.

Impact of a steamer should be tested in a small section before steaming the entire area to determine the speed of treatment. Typically, it is recommended that you spend 10 to 15 seconds passing the steam head across the surface of one foot of space. Studies have shown that steamers kill 100 percent of eggs, nymphs, and adults on mattress surfaces. Under bed sheets and sofa fabric, steamers kill 90 percent of eggs, nymphs, and adults when treated for approximately 20 seconds. Also, steamers kill eggs, nymphs, and adults in cracks when treated for more than 4 seconds. Steamers do not kill eggs, nymphs, or adults under leather sofa covers.

Whole Room Heat or Cold Heat treatment is an effective and quick method to control bed bugs. Commercial heating services treat infested items or rooms using portable heaters and fans to control temperature. Recommendations for treatment efficacy is to heat the room to at least 140°F for two hours or 130°F for three hours. If humidity can be controlled, 20-30 percent humidity in combination with 130°F can kill eggs, nymphs, and adults in 30 minutes. The appropriate sealing of doors and windows improves treatment efficiency by preventing the escape of the heat and bed bugs.
Chemical Control

Chemical control is the most common approach to managing bed bug infestations. However, relying on insecticides alone might require a greater amount of the product which can lead to insecticide resistance. In addition, labels prohibit the use of insecticides on some bed bug-preferred areas, such as mattresses and couches, because people may come into direct contact with the chemical. Also, insecticides cannot be applied on fabric items such as sheets, pillows, blankets, and clothes.

IPM programs, especially those that combine chemical and mechanical approaches, are effective to control bed bugs. For example, some companies that use whole room heat treatment recommend insecticide application in places where bed bugs would walk and rest to avoid re-infestations. Other companies use insecticides on resting areas (such as bed frames, box springs, inside empty dressers, and cracks) in combination with vacuuming and steam (on beds and couches).

Approximately 300 products in the following categories are registered to control bed bugs.

Pyrethrins and Pyrethroids Pyrethrins and pyrethroids are the most common active ingredients to control bed bugs. They have low toxicity to humans and birds. Pyrethrins are a natural compound produced by plants of the genus chrysanthemum; they provide a quick knockdown but little long-term control of bed bugs. In contrast, pyrethroids are synthetic insecticides based on pyrethrins; they are highly effective against bed bugs. Pyrethroids also act as a repellent. However, studies have reported that bed bugs might develop insecticide resistance to pyrethrins and pyrethroids.

Neonicotinoids Neonicotinoids are systemic insecticides based on nicotine, which is a natural compound produced by tobacco and other plants of the Solanaceae family. They have low toxicity to humans and birds and can be used on those bed bug populations with resistance to pyrethroids. Also, several insecticides registered to control bed bugs are mixtures of pyrethroids and neonicotinoids.

Insect Growth Regulators Insect growth regulators (IGRs) are chemicals that mimic juvenile growth hormones in insects. IGRs usually kill bed bugs during the molting process when they shed their "skin."

Biopesticides A group of scientists at Penn State University registered a biopesticide, called Aprehend, to control bed bugs based on a natural fungal disease Beauveria bassiana Strain GHA (see Figure 10). This biopesticide contains fungal spores in an oil formulation which is sprayed in strategic bands or barriers where bed bugs will walk, such as the sides of box springs or couches. Bed bugs contact the spores when crossing treated areas. The bed bugs infested with spores then act as carriers, thereby transferring the spores by contact to other individuals. Spores germinate in approximately 24 hours, penetrate directly within the bed bugs’ bodies, and develop in their circulatory systems. Bed bugs in contact with the spores will die in four to seven days. Beauveria bassiana is a fungus naturally present in the environment that will not harm humans, pets, or furniture. However, this biopesticide cannot be applied to mattresses, sheets, pillows, blankets, comforters, and other surfaces where people may come into direct contact with it. Read and follow the label for more details.

Pyroles Pyroles are pro-insecticides, which are metabolized into active insecticides after entering the host. Pyroles disrupt certain functions in the bed bug’s cells, causing its death. Chlorfenapyr is an example of a pyroles active ingredient registered to control bed bugs.

Botanical Oils Botanical oils are plant-based insecticides. They intoxicate bed bugs but have low insecticide residues. Some neem oil insecticides are registered to control bed bugs.

Desiccants Desiccants absorb moisture from the air to induce or sustain a state of dryness. On bed bugs, desiccants destroy the waxy, protective outer coating, which causes desiccation. When using desiccants to control bed bugs, it is critical to only use those products that are registered by the EPA and labeled for bed bug control to reduce inhalation risk to people.

Chemical Formulations Active ingredients are available in different formulations (see Figure 11). Liquid is the most common formulation to control bed bugs. Products in liquid formulations can be applied directly to infested areas such as cracks, crevices, bed frames, baseboards, and other similar sites. Pyrethroids, neonicotinoids, IGRs, and botanic oils are examples of insecticides in liquid formulations.
Products with dry formulations are also effective but they should be limited to cracks and crevices. For example, diatomaceous earth and boric acid are desiccant insecticides in dry formulations labeled to control bed bugs.

Fumigants might also be highly effective to control bed bugs, but in Pennsylvania, fumigants can only be applied by a professional certified applicator with Category 13 (Structural Fumigation). Sulfuryl fluoride is the only active ingredient registered for structural fumigation in Pennsylvania.

Finally, aerosols and foggers have shown low efficacy against bed bugs.

**Citations**

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Penn State College of Agricultural Sciences research and extension programs are funded in part by Pennsylvania counties, the Commonwealth of Pennsylvania, and the U.S. Department of Agriculture.

Where trade names appear, no discrimination is intended, and no endorsement by Penn State Extension is implied.